Other Regional Structures

Other regional structures besides faults include folds and joints. Regional folds generally trend in the same northwest direction as the regional faults. Some of the folds, such as Corning and Dunnigan Hills, are probably the surface expression of deeper movements along faults. Regional folds are consistent with a compressive stress regime oriented about N75E.

The largest structure is the synclinal fold of the Sacramento Valley. On the west side, the Cretaceous mudstone, sandstone, and conglomerate dip moderately to steeply east and strike northwest. On the east side, similar beds dip to the west and strike in about the same direction.

The Chico monocline occurs along the east side of the valley between Chico and Red Bluff. Along the east side, beds dip shallowly to the west, but at the axis of the monocline, the beds dip more steeply toward the center of the valley. The axis is also displaced by numerous faults trending parallel to the axial plane.

Jointing is pervasive in the GVS but is generally not present in rocks younger than the Cretaceous. The Cretaceous mudstones are generally the most jointed. Jointing sets in three directions, and spacings from less than an inch to about a foot are common. The joint directions are perpendicular to each other with one set parallel to the bedding and the other two sets perpendicular to the bedding and to each other. The pervasive jointing causes the exposed mudstone outcrops to slake readily.

The Cretaceous sandstones and conglomerates vary in joint spacing depending mostly on the thickness of the individual beds. Joint directions are similar to the mudstones. The massive units have joint spacings ranging from a few feet to several tens of feet or more.

Seismicity

The seismicity of the western Sacramento Valley foothills has been recorded by a number of different agencies over the last 100 years. These agencies include the University of California, Berkeley, the California Department of Conservation, USGS, and DWR. The accuracy in the measurements of the epicenters, focii, and magnitude has improved over the years as more instruments with greater sensitivity and accuracy have been installed. The older data were recorded with instruments located several hundred miles away. Consequently, the plotted locations of seismic events may be off by tens of miles.

Earthquakes as small as M1 and M2 have been recorded in the project area since the installation of the Northern California Seismic Network beginning in 1975 (Attachment A). The appendix includes an analysis of earthquake activity to date. DWR, in 1991, as part of the Red Bank Project, worked with USGS to install four additional seismic stations in the area. Accuracy in the plotting of epicenters with the data from these stations can be within several miles for relatively small earthquakes occurring close by. USGS provided DWR with an analysis of the data recorded to date by the network.

According to USGS, the number of earthquakes recorded by the network is typically three or less and often zero per month.

Historical Earthquakes

Historical seismic activity for the last 200 years or so in the central and northern part of the Sacramento Valley has been low to moderate compared to other areas of California. Events in Northern California larger than M6 have occurred in the San Francisco Bay region, near Eureka, north of Tahoe, and in the Vacaville-Winters area. Events larger than M7 occurred in Eureka in 1923 and 1992, and in the San Francisco area in 1868, 1906, and 1989.

Major fault zones known to be seismically active near the project area include the Foothills fault system, the Chico monocline, the blind thrusts of the Great Valley fault, the Willows and Corning faults, the Bartlett Springs, Maacama, and San Andreas faults, and the Cascadia subduction zone.

The Winters-Vacaville earthquakes of April 19-21, 1892, are the two earthquakes with the most significant impact on the design of the proposed projects, particularly Thomes-Newville, Sites, and Colusa. This is because the proposed dams and structures are overlying the same Great Valley fault (Coast Ranges-Sierra Nevada block boundary) that is believed to have been the cause of the earthquakes. This zone is believed to extend the entire length of the greater Central Valley. A similar temblor (M6.7) to the Winters-Vacaville earthquakes occurred in 1983, causing considerable damage in the Coalinga area.

The two major Winters-Vacaville temblors and numerous aftershocks produced widespread damage throughout much of Solano, Yolo, and Napa Counties. The towns of Winters, Vacaville, and Dixon suffered massive destruction with intensities reaching MM IX and estimated magnitudes between six and seven (DWR 1978).

On January 7, 1881, an estimated M5 occurred east of Red Bluff at the edge of the Cascade Range. On June 6, 1884, an estimated M5 occurred near or north of Red Bluff. One wall cracked. An M4.5 occurred in the Willows area on July 24, 1903, with some cracking and falling plaster. An MM VI event occurred on April 16, 1904, south of Redding. An M5.7 occurred northeast of Chico on February 8, 1940, and an M4.6 near Chico in 1966. Both of these were probably associated with the Chico monocline. An M4.7 event occurred on April 29, 1968, near Willows (Wong 1988).

On August 1, 1975 an M5.7 occurred near Oroville on the Cleveland Hills fault. This quake renewed interest in the Foothills fault system and speculations about RIS related to Lake Oroville.

Several earthquakes have occurred fairly recently near Redding, Chico, Cottonwood, and Willows. A series of earthquakes, including an M5.2 that occurred in November 1998, struck the Redding area over a period of months. Historic earthquakes of M6+ have occurred both in the valley and in the Coast Ranges to the west.

Earthquake Design Criteria

The MCE measure is used because the likelihood of such earthquakes occurring is great enough, and the probability of certain faults being active and their recurrence rates are not known for most faults. The MCE implicitly takes into account such factors. The resultant ground motions from MCE are the most appropriate consideration for critical structures and for public safety because they are considered to be conservative.

Hazards relating to earthquakes include surface rupture, soil liquefaction, and shaking. Generally, ground shaking is the predominant source of earthquake damage, resulting in 90 percent or more of the damage; but in areas with liquefaction potential, damage can increase commensurately. Surface rupture generally results in less than 5 percent of the damage. Neither surface ruptures nor liquefaction is considered to be a likely cause of damage to the proposed projects.

The magnitude or local magnitude of an earthquake is defined as the logarithm to the base 10 of the amplitude, in microns, of the largest trace deflection observed on a standard torsion seismograph at a distance of 100 km from the epicenter. The moment magnitude is a newer concept calculated from modern seismographs, taking into account all the seismic waves; or it can be estimated based on the rupture area (M_W=4.07+0.98log(lw)). This estimated value is used when historic earthquakes or potential earthquakes lacking instrument data are evaluated.

CDMG (1996) published a probabilistic seismic hazard map showing peak horizontal ground acceleration on uniform soft-rock sites. The values have a 10 percent probability of exceedance in 50 years. Acceleration at 10 percent in 50 years ranges from about 0.1 to over 1g. The map shows that the damsites lie in a zone with a 50-year recurrence interval of between 0.1 and 0.3 g. CDMG also developed a map showing areas that are thought to have experienced an intensity of MM VII or greater between 1800 and 1996. This includes most of the north coastal area but is somewhat west of the proposed damsites.

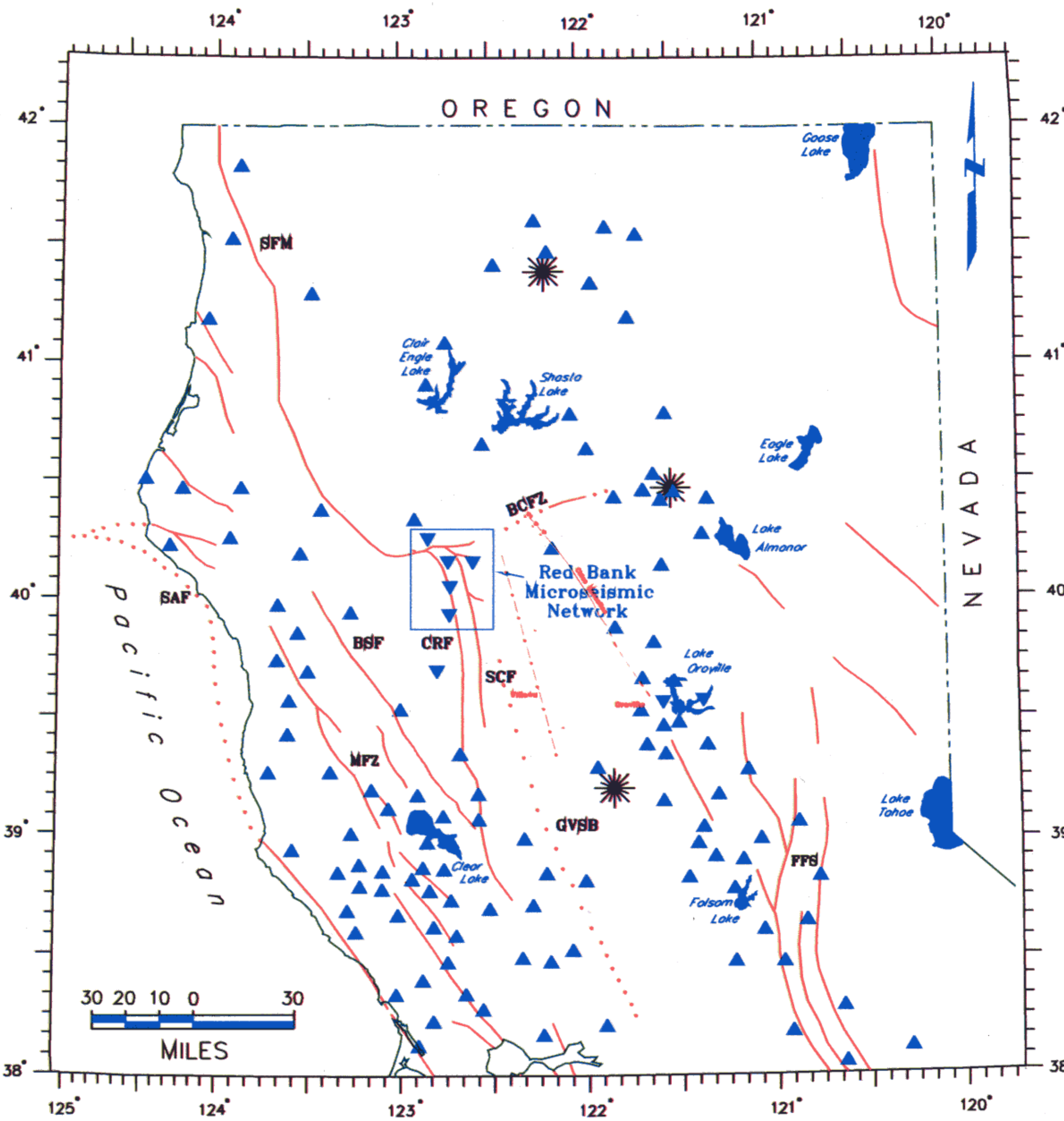
Seismic Stations and Microseismic Networks

Figure 9 shows the seismic stations in Northern California. The majority of stations are clustered around preexisting reservoirs such as Lake Shasta, Lake Oroville, Stony Gorge Reservoir, and Clear Lake.

Figure 10 shows the epicenter data for the north-central part of the Sacramento Valley. Sources of data include DWR (1900-1949, M_L>3), U.C. Berkeley (1950-1970, M_L>3), and USGS (1970 to present, M_L>1). Earthquakes of M_L>4 are fairly rare, averaging about one per year. Smaller quakes between M1-3 are more common, averaging two to three per month.

Figure 10 shows earthquakes from one of several seismic networks that have operated intermittently. These include the survey's main network, the Shasta Dam network, and the DWR network. The data shows the date, time, location, hypocentral depth, maximum intensity, and local magnitude of each earthquake. Accuracy of location and magnitude is dependent on the density and geometry of the seismic stations existing at the time of the event.

A microseismic network was installed in 1991 and is maintained by USGS as part of the Red Bank Project investigation to fill in the gap between Stony Gorge Reservoir and Lake Shasta. The purpose was to monitor and analyze microearthquakes to assist in defining hidden faults along the Coast Ranges-Sierra Nevada block boundary and to determine whether this zone extended this far to the north. The network consists of five additional stations in the Red Bank area



Legend

Map Symbols

Fault: Faults are dashed where approximate, and dotted where concealed

USGS Seismic Stations

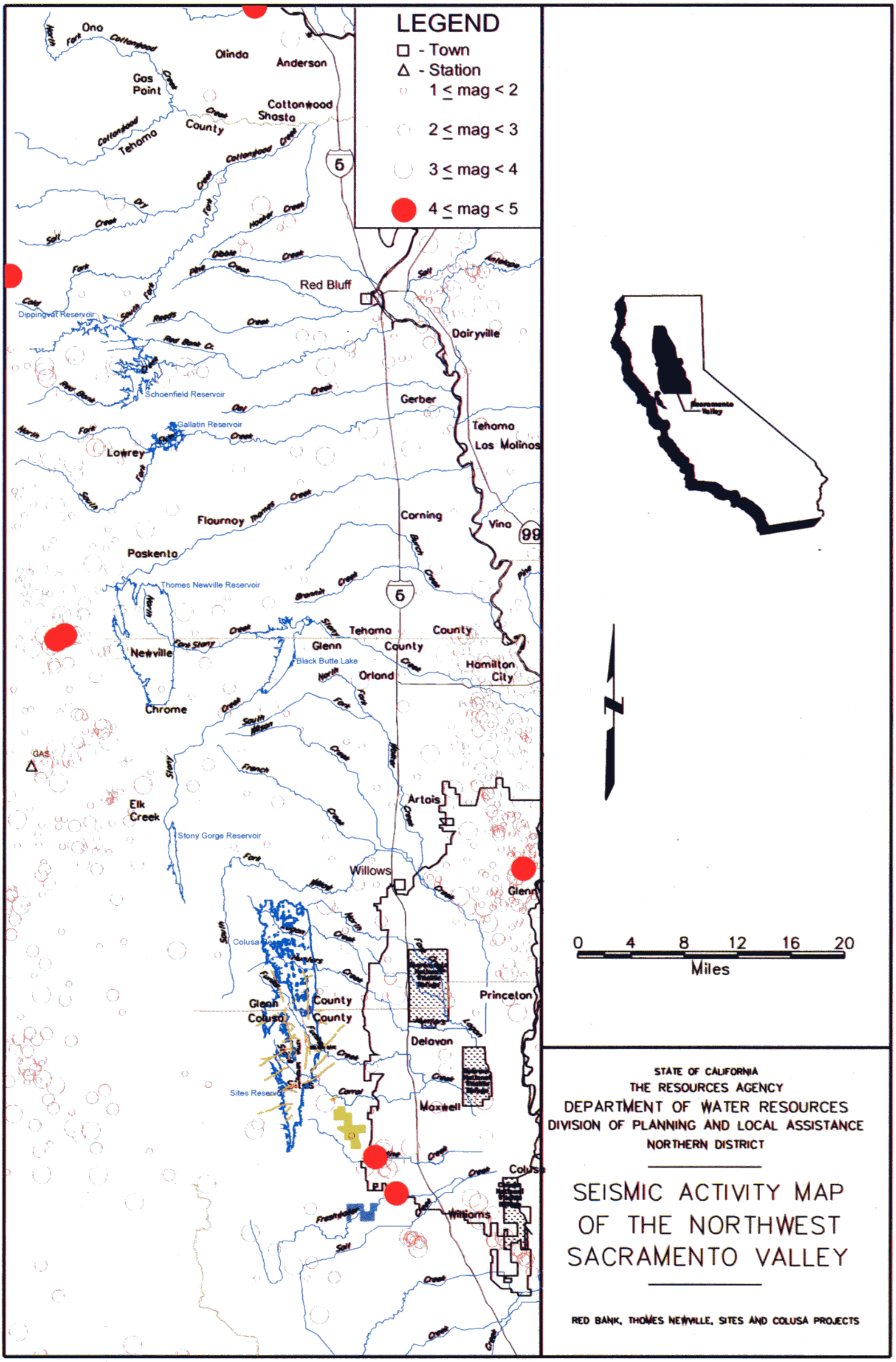
DWR Seismic Stations

Volcano

Faults

SAF = San Andreas Fault
CRF = Coast Range Fault
SCF = Stony Creek Fault
FFS =Foothills Fault System
MFZ = Maacama Fault Zone
BCFZ = Battle Creek Fault Zone
SFM = South Fork Mountain Fault
GVSB = Great Valley Sierran Block Boundary
BSF = Bartlett Springs Fault

Figure 9. Location of Seismic Stations in N. California



STATE OF CALIFORNIA
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DIVISION OF PLANNING AND LOCAL ASSISTANCE
NORTHERN DISTRICT

SEISMIC ACTIVITY MAP OF THE NORTHWEST SACRAMENTO VALLEY

RED BANK, THOMES NEWVILLE, SITES AND COLUSA PROJECTS

N: geo\projects\SitesDam\seismic\activity.dwg that are shown on Figure 10. DWR receives their reports quarterly and enters the information into an appropriate database. A summary of the data is in Attachment A.

USBR installed a 10-station microseismic network in the Shasta-Trinity area in 1982. The network has provided hypocenter information on magnitudes as low as 0.2. Two older stations operated by U.C. Berkeley are at Whiskeytown Dam and at Mineral near Mt. Lassen.

Northern California Earthquake Potential

There are a number of different methodologies for estimating earthquake ground motion parameters. These include: simple prescribed parameter values, selection of a design strong-motion record, probabilistic seismic hazard analysis, and deterministic seismic hazard analysis. The latter two types were done for this study.

Probabilistic Seismic Hazard Analysis

This type of analysis is site-specific. According to CDMG (1997, Web site), this includes the following:

- Compiling a database of potentially damaging earthquake sources, including known active faults and historic seismic source zones, activity rates, and distances from project sites. This should include a comparison with published slip rates. Differences in slip rates should be documented and the reasons for them explained.
- Using published maximum moment magnitudes for earthquake sources, or estimates that are justified, well documented, and based on published procedures.
- Using published curves for attenuation of peak ground acceleration with distance from the earthquake source as a function of earthquake magnitude and travel path.
- Evaluating likely effects of site-specific response characteristics from soft soils, topography, and near-source effects.
- Characterizing the ground motion in terms of peak ground acceleration with a 10 percent probability of exceedance in 50 years, taking into account historical seismicity, available paleoseismic data, the slip rate of active faults, and site-specific resonance characteristics.

A probabilistic seismic hazard working group on Northern California earthquake potential was convened in 1994 as part of the USGS National Earthquake Hazards Reduction Program. The working group was composed of many scientists from academia, government, and private industry, including CDMG (1996) and USGS (1996). The task of the working group was to create a map and database of active faults, both surficial and buried. The database contains 62 potential Northern California sources, including fault segments and areal-distributed zones. Factors considered include broadly-based plate tectonics, geologic slip rates, geodetic strain rates, and microseismicity. The hazard maps form the basis for the ground motion design maps of the 1997 edition of the *National Hazard Reduction Program Recommended Provisions for Seismic Regulations for New Buildings*. Maps and databases developed by the working group are on CDMG's Web site (see References).

Because of the brief historical record of earthquakes, a standard methodology was used, based on the empirical relationships between fundamental earthquake parameters (USGS 1996), including the following:

- Fault segmentation or determination of source length (l) - The fault rupture length is generally related to the size of the earthquake.
- Fault down-dip width (w) - Dip width is generally assumed to be 12 km in Northern California, except where more accurate data from microearthquakes or other sources are available.
- Historical values of magnitude (M_W) - Historical values were used where available: otherwise the empirical relation of the moment to rupture area M_W=4.07+0.98log(lw)(km^2) was used.
- Average coseismic slip (d) - Historical values were used when available; otherwise the relationship between seismic moment and moment magnitude was used to determine d.
- Long-term slip rate (r) - Only minimum values on a few faults are available for this measurement. The values are provided in ranges that are a measure of the reliability.
- Recurrence time (t) - Historic values were used when possible, otherwise the empirical relation t=d/r was used, where d is the average coseismic slip and r is the slip rate.

CDMG (1996) published a *Probabilistic Seismic Hazard Map (10 percent probability in 50 years) of Peak Horizontal Ground Acceleration in Uniform Soft-Rock Site Conditions.* This is shown on the CDMG Web site. The map shows that the project damsites fall within the 0.1 to 0.3g zone. It is important to note, however, that a 50-year recurrence interval is too small for such a large and important structure as a large dam, since the consequences of failure are too large. For these structures, a deterministic approach is generally adopted.

Deterministic Seismic Hazard Analysis

Deterministic evaluation (CDMG Web site) of seismic hazards includes the following:

- Evaluating potentially damaging earthquake sources and deterministic selection of one or more suitable "controlling" sources and seismic events. The magnitude for any fault should be the maximum value that is specific to the seismic source. Maximum earthquakes may be assessed by estimating rupture dimensions of the fault.
- Using published curves for the effects of seismic travel paths using the shortest distance from the sources to the sites.
- Evaluating the effects of site-specific response characteristics on either site acceleration or cyclic shear stresses within the soils of interest.

Caltrans published a deterministic map in 1996 based on the MCE and accompanying text detailing the latest understanding of earthquake science and earthquake engineering. The work was apparently done independently of USGS and CDMG work. Also, the potential for an M8+ on the Gorda plate-Cascadia subduction zone was not considered. This probably affected the predicted peak horizontal acceleration for the Red Bank Project, but not the Thomes-Newville, Sites, and Colusa Projects.

DSOD uses a deterministic approach. This method includes setting an MCE for the project and determining the peak acceleration based on the horizontal distance, the predominant period for the maximum acceleration, and the bracketed duration of the shaking.

Table 2 shows the published information regarding peak horizontal acceleration, MCE, and acceleration probabilities for each of the project damsites. This is based on the Caltrans California Seismic Hazard Map 1996 which shows major active faults and contours of expected peak acceleration. Also shown is the M_W earthquake based on the Great Valley fault system segmentation model (CDMG 1996). The last column is the 10 percent probability in 50 years that the peak horizontal acceleration will equal or exceed the predicted value on soft-rock site conditions (CDMG 1996).

Table 2. Published Seismic Criteria for Project Damsites Source: CDMG 1996, Caltrans 1996

Damsite	Creek	Peak Acceleration Caltrans 1996 (g)	M_W CDMG 1996	10% in 50 years CDMG 1996 (g)
Dippingvat	S.F. Cottonwood	0.4-0.5	6.7	0.1-0.2
Schoenfield	Red Bank	0.4-0.5	6.7	0.1-0.2
Newville	N.F. Stony	0.6+	6.7	0.1-0.2
Grindstone	Grindstone	0.4-0.5	6.7	0.2-0.3
Logan	Logan	0.4-0.5	6.7	0.1-0.2
Hunters	Hunters	0.4-0.5	6.7	0.1-0.2
Golden Gate	Funks	0.5-0.6	6.7	0.2-0.3
Sites	Stone Corral	0.5-0.6	6.7	0.2-0.3

Caution should be used in applying these criteria to dam designs. The highest peak acceleration shown on the Caltrans map is 0.6g. This is a realistic value for most instances. However, surprisingly high peak accelerations exceeding 1g have been recorded in several instances during recent earthquakes such as San Fernando and Northridge. Caltrans does not imply that the 0.6 is the maximum possible, but rather to indicate the least controversial upper level of peak acceleration known to occur.

USBR (1986) published a seismotectonic study of the northernmost part of California for its project features. The seismographs show a variety of fault plane solutions from 1983-84 network data but mostly strike-slip faulting from north-south compression or east-west extension. Whether extension or compression is the causative stress in the Shasta area cannot be determined from the current information. There is also no evidence in the seismic patterns to determine the orientation of the fault planes. Clusters, however, do identify localized zones where stress is being released. The seismicity does not appear to correspond with faults or geologic structures mapped on the surface.

Reservoir-Induced Seismicity

Increased earthquake activity has been associated with the filling of a number of reservoirs. From a total of 64 cases of possible RIS reported worldwide prior to 1983, 45 were classified as actual cases (HMT 1983).

The magnitude of RIS is a function of the location, depth, and size of a reservoir, and seismic activity in the area. The two main RIS triggering mechanisms appear to be the increased stress from loading the reservoir area, and the increased pore pressure from seepage. Both of these factors relate directly to reservoir height and volume, with height probably being more important than volume. Data indicate that RIS is most common in reservoirs greater than 300 feet in height in regions that are seismically active.

RIS is believed to be a consideration for all of the proposed reservoirs because of the large volume of water and depths that could exceed 300 feet. An M6.5 earthquake occurring directly under a damsite at a depth of about 6 miles is believed to be a conservative estimate of this type of event. This is based on numerous RIS events ranging from M5 to M6.5 that have been documented worldwide.

The RIS event is smaller than other potential earthquakes related to the Great Valley fault or Gorda plate subduction that could occur at the damsites, and therefore are not considered to be the source of the Design Earthquake.

Project Design Earthquakes

Project Design Earthquakes are based on the deterministic approach and the occurrence of an MCE. Design Earthquakes are based on a number of factors, including the occurrence of historic earthquakes and concern for public safety as described in previous sections. The earthquakes were selected to present a conservative estimate of the MCE.

Red Bank Design Earthquake

Three types of earthquakes were considered for the Red Bank Project. The first is an M6.5 RIS event occurring at a depth of 10 km directly under the dam. The second is a Great Valley fault rupture, in this case, of several segments resulting in an M7 event directly under the dam at a depth of 10 to 12 km. The third is a Gorda plate event of M8.3 at a depth of 35 km directly underneath the dam. Table 3 shows the design parameters developed from these events using graphs by Seed and Idriss (EERI 1982). The Gorda plate event has the highest peak acceleration and the longest duration and is considered the Design Earthquake for the Red Bank Project. Because of the deep source area of 35 km, the depth was used as a distance to determine the attenuated acceleration, duration, and period. It should also be noted that the chances that a Gorda plate earthquake would occur directly under the project are extremely remote.

Table 3. Draft Preliminary Design Parameters for the Red Bank Project

Earthquake Source	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Reservoir-Induced Seismicity	6.5	0	10	0.69	19	0.28
Great Valley Fault	7	0	10	0.70	26	0.32
Gorda Plate	8.3	0	35	0.72	28.5	0.42

* Note: Preliminary design parameters are subject to change as new information becomes available. These parameters are believed to be conservative.

Thomes-Newville Design Earthquake

Three types of earthquakes were considered for the Thomes-Newville project. The first is an M6.5 RIS event occurring at a depth of 10 km directly under the dam. The second is a Great Valley fault rupture, in this case, of several segments resulting in an M7 event directly under the dam at a depth of 10 to 12 km. WLA (1997) believes the M7 is very conservative, but that the earthquake could nucleate at a shallower depth, possibly 6 km. The third event is an M6.5 on the Stony Creek fault (ESA 1983). A Gorda plate event was not considered because it is believed that the southern edge of the plate boundary is postulated to be near Red Bluff. The Coast Ranges and Stony Creek faults are generally not considered active, although some moderately deep earthquakes may be associated with them. The Bartlett Springs fault is active but is about 40 km to the west, too far away to be the Design Earthquake. The Great Valley fault encompasses a wide zone of deformation and is considered to be active because of the Winters-Vacaville earthquakes of 1892. The conservative scenario is that an M7 could occur directly under the proposed dam.

Table 4 shows the design parameters for the Thomes-Newville project. The M7 Great Valley fault earthquake has the highest acceleration and the longest duration and is therefore considered the Design Earthquake. The Seed and Idriss (EERI 1982) curves, using a distance of zero, were used to estimate the acceleration, duration, and period.

Table 4. Draft Preliminary Design Parameters for the Thomes-Newville Project

Earthquake Source	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Reservoir-Induced Seismicity	6.5	0	10	0.69	19	0.28
Great Valley Fault	7	0	10	0.70	26	0.32
Bartlett Springs	7.1	40	10	0.17	23.5	0.32
Stony Creek Fault	6.5	6	10	0.28	19	0.28

* Note: Preliminary Design parameters are subject to change, as new information becomes available. These parameters are believed to be conservative.

Sites and Colusa Projects Design Earthquake

Three types of earthquakes were considered for the Sites and Colusa Projects. The first is a RIS of M6.5 occurring at a depth of 10 km. The second is an M7.1 occurring on the Bartlett Springs fault at a distance of 40 km. The third is a Great Valley fault multiple-segment rupture with an M7 occurring at a depth of 10 km. Table 5 summarizes the design parameters. The M7 Great Valley fault event is considered to be the design earthquake. WLA (1997) considers the M7 to be very conservative, but the site-source distance may be somewhat less. Directivity effects may be significant in estimating ground motions.

Table 5. Draft Preliminary Design Parameters for the Sites and Colusa Projects

Earthquake Source	Maximum Credible Earthquake (M_W)	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Reservoir-Induced Seismicity	6.5	0	10	0.40	19	0.28
Great Valley Fault	7	0	10	0.70	26	0.32
Stony Creek Fault	6.5	16	10	-	-	-
Bartlett Springs	7.1	32	10	-	-	-

* Note: Preliminary Design parameters are subject to change as new information becomes available. These parameters are believed to be conservative.

Damsite Geology And Surface Rupture Hazards

CDMG (1996) published guidelines for evaluating the hazards of surface fault ruptures. The guidelines include a suggested report outline on faults, the types of exploration methods, and a comprehensive list of references. The study of the potential hazards of surface fault ruptures is based partially on the concepts of recency and recurrence, with the more recent the faulting and the higher the recurrence interval, the greater the probability for future faulting.

This Phase I report is a summary of past investigations and does not include any current field investigations. Phase II will include detailed mapping, trenching, drilling, and stereo aerial photo, side-looking radar, and low-sun-angle photography analyses. The Red Bank Project was initially investigated by DWR (1991) between 1989 and 1991. The Thomes-Newville Project was investigated between 1980 and 1983 by DWR (1980) and ESA (1980). USBR investigated the Sites Project between 1969 and the mid-1980s. No damsite geology has been done for the Colusa Cell Project.

Red Bank Project

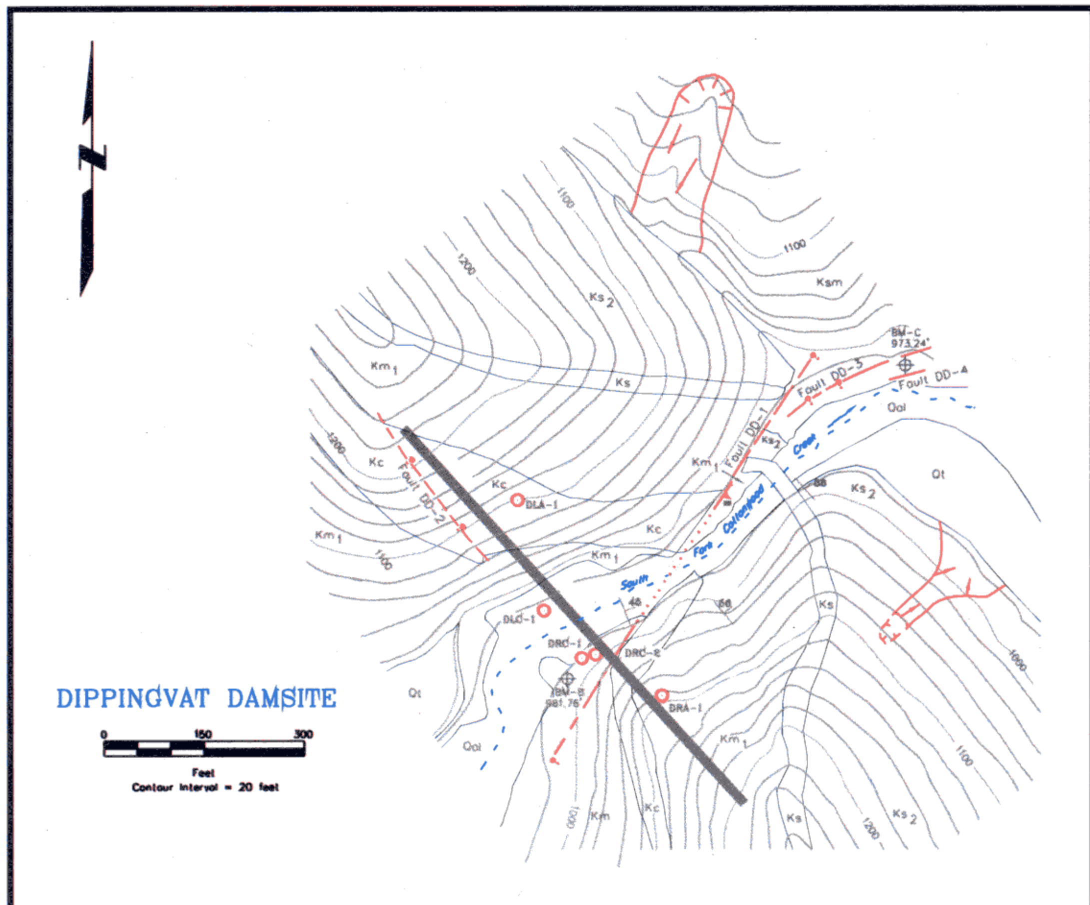
The Red Bank Project was initially envisioned as a number of earthfill structures. Advances in the use of roller compacted concrete (RCC) created renewed interest in the project (DWR 1987). The faulting and seismicity was investigated in detail by DWR (1991) and a summary is provided here. Figure 11 shows the damsite foundation areas, simplified geology, and faulting in the Red Bank area. Two small diversion structures, Bluedoor and Lanyan, are not discussed in the text.

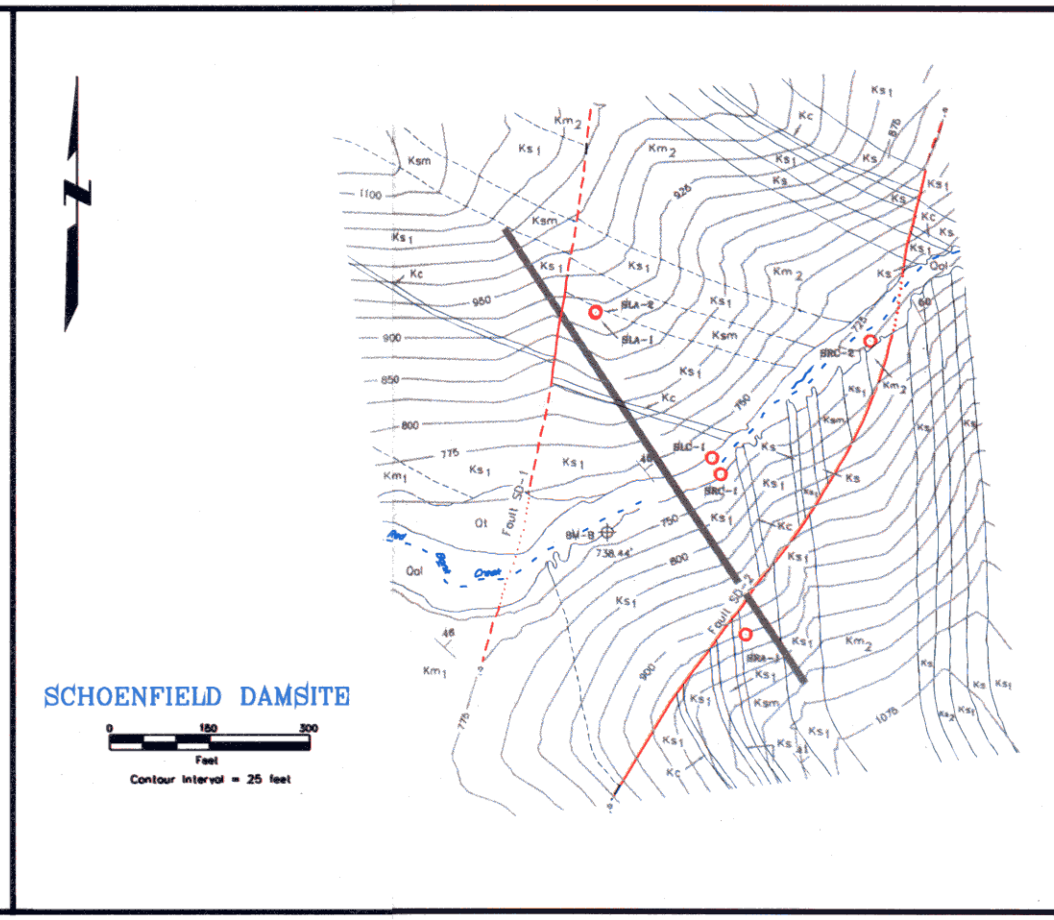
Dippingvat Dam Site

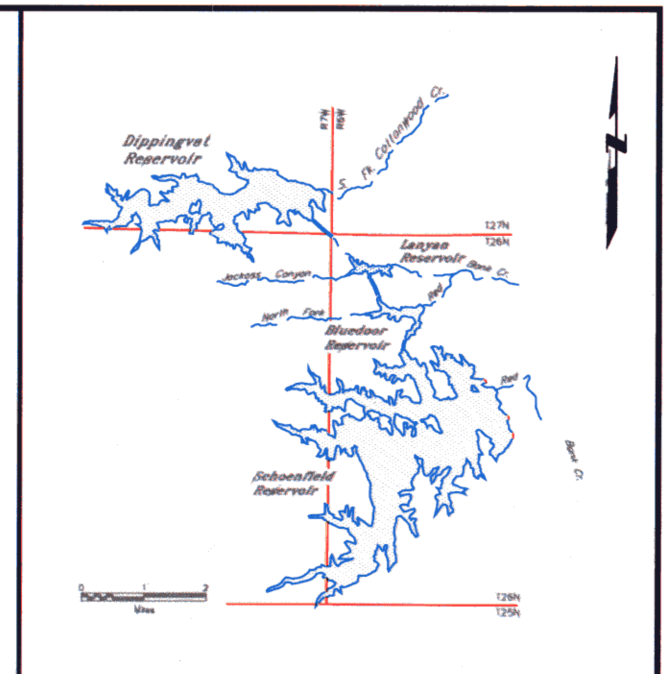
Dippingvat is in a narrow gorge on South Fork Cottonwood Creek. The proposed dam is a 256-foot-high RCC structure impounding 104,000 acre-feet. The damsite is on Upper Cretaceous (Turonian) conglomerate (39 percent), sandstone (6 percent), and mudstone (55 percent). The beds dip downstream 45 to 65 degrees and strike northwest.

Quaternary and Recent deposits include minimal stream channel deposits averaging about 2 feet thick and colluvial soil along the base of the abutments averaging from about 5 to a maximum of 15 feet. Terrace deposits are found both upstream and downstream of the axis.

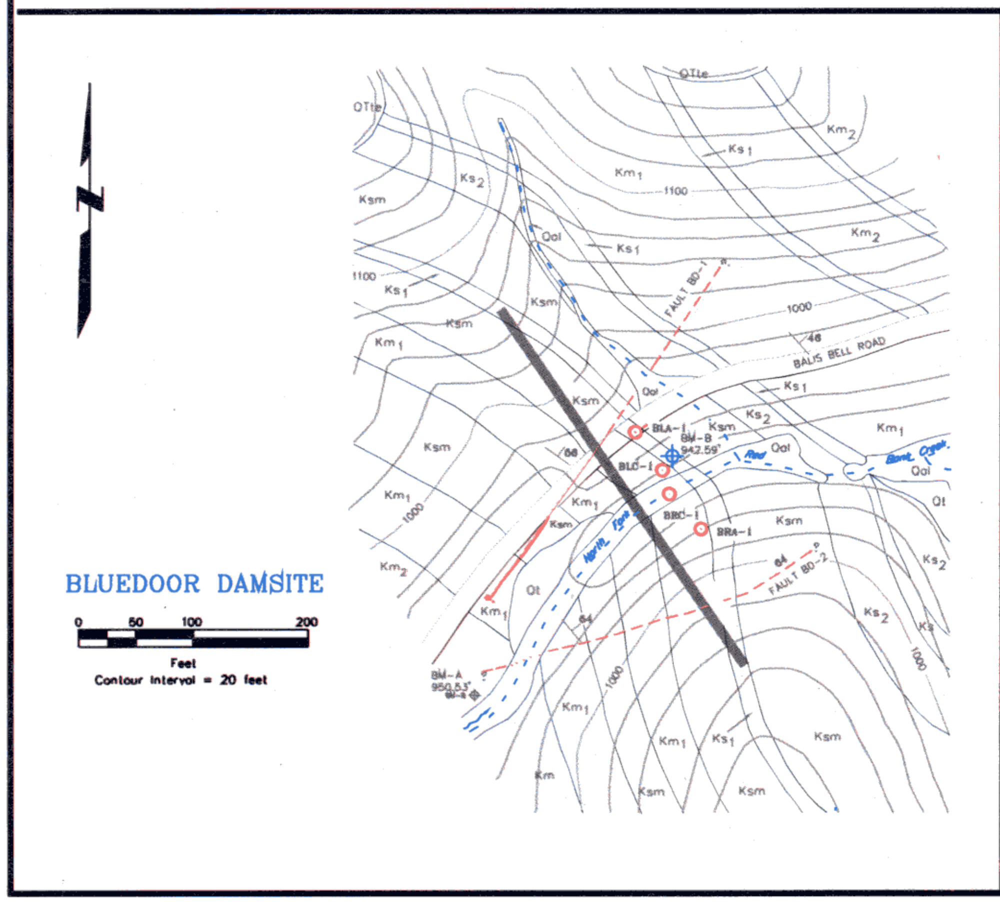
Three faults are exposed in the foundation. All were intersected during drilling. Associated with the faults were narrow zones of gouge and sheared mudstone. Fault DD-1 bears diagonally (N25W) across the channel at the dam axis. The fault can be traced at least 700 feet, with an apparent horizontal offset of 75 to 100 feet, and a width of 3 feet. Fault DD-2 trends N40W and offsets a conglomerate bed on the left abutment. It is poorly exposed but drilling intersected a number of narrow shears, each less than a foot wide, which may be associated with this fault. Fault DD-3 is about 300 feet downstream of the axis. This fault is a zone of fracturing with minimal offset. The faults do not cross datable Quaternary deposits. DWR (1991) concluded that the faults were pre-Quaternary in age and would not create a seismic or surface rupture hazard.

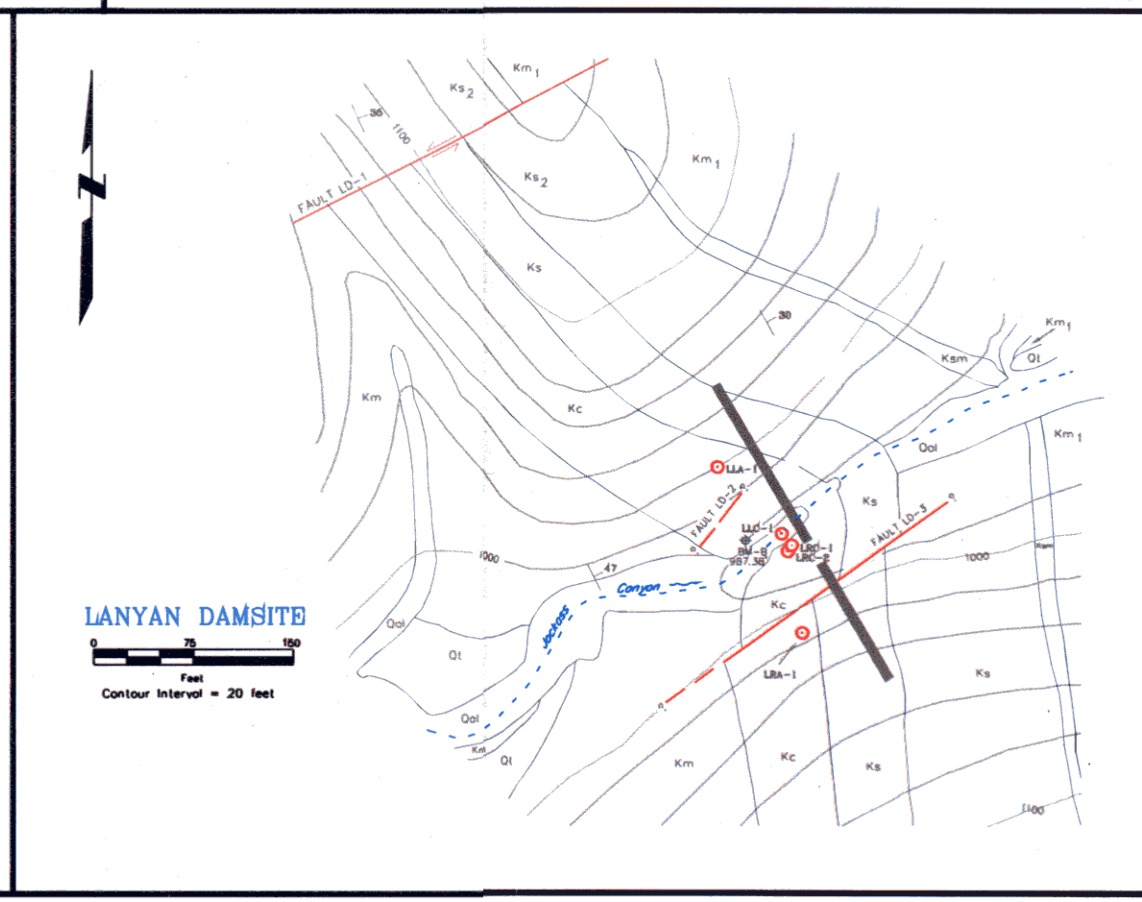






Location of Proposed Project Features





Legend

QUATERNARY

Qal	Recent alluvium – mostly sand, gravel, and cobbles; includes small exposures of bedrock.
Qt	Terrace deposits – mostly sand, gravel, and cobbles mantled by clayey soil.
QTte	Tehama Formation – semi-consolidated sand, silt and clay with gravel lenses.

CRETACEOUS – Great Valley Sequence

Ks	100% Sandstone
Ks_1	80–100% Sandstone with rare mudstone interbeds.
Ks_2	60–80% Sandstone with mudstone interbeds.
Ksm	40–60% sandstone intbd with mudstone.
Km_1	80–100% mudstone with rare sandstone interbeds.
Km_2	60–80% mudstone with sandstone interbeds.
Kc	Conglomerate

Geologic Contact, Dashed Where Approximate.

30 Strike and Dip of Bedding

Fault, Dashed Where Approximately Located, Dotted Where Concealed, Queried Where Uncertain, Arrows Showing Apparent Direction of Movement.

Landslide, Dashed Where Approximately Located.

BM–B 973.24' DWR Survey Benchmark, and Elevation.

SRC–2 Drill Hole Location

Geology modified from Engineering Geology of the Red Bank Project, 1990, DWR
Edited by Pamela Mills, 6/98 N:/geo/projects/sites/maps/Redplate.dwg

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THE RESOURCES AGENCY
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NORTHERN DISTRICT

Red Bank Reservoir Project Damsite Geology

Schoenfield Dam Site

The Schoenfield Dam site is in a narrow and steep gorge on Red Bank Creek. The proposed dam would be a 300-foot-high RCC structure. The dam foundation consists of Upper Cretaceous (Turonian) sandstone (82 percent), mudstone (14 percent), and minor conglomerate (4 percent), with the bedding thickness varying from less than one inch to tens of feet. The beds trend northwest and dip about 60 degrees to the east.

Quaternary to Recent deposits consist of minor stream gravel in the channel and some colluvium at the base of the abutments. Terrace deposits 4- to 8-feet thick occur both upstream and downstream of the axis within the foundation area.

There are two mapped faults and several smaller faults that intersect the foundation area. All are transverse faults that are roughly perpendicular to the regional strike of bedding. Fault SD-1 cuts the dam axis at N15E high on the left abutment and has an apparent right lateral offset of 45 feet. The fault is poorly exposed and does not appear to have great lateral extent. A small terrace lies across the fault trace but no trenching was done. SD-2 is more prominent, trends N25E, and cuts through the right abutment. Movement appears to be right-lateral with a displacement of about 75 feet. The fault consists of highly sheared and slickensided fault gouge. The faults do not cross datable Quaternary deposits. DWR (1991) concluded that the faults were pre-Quaternary in age and would not create a seismic or surface rupture hazard.

Thomes-Newville Project

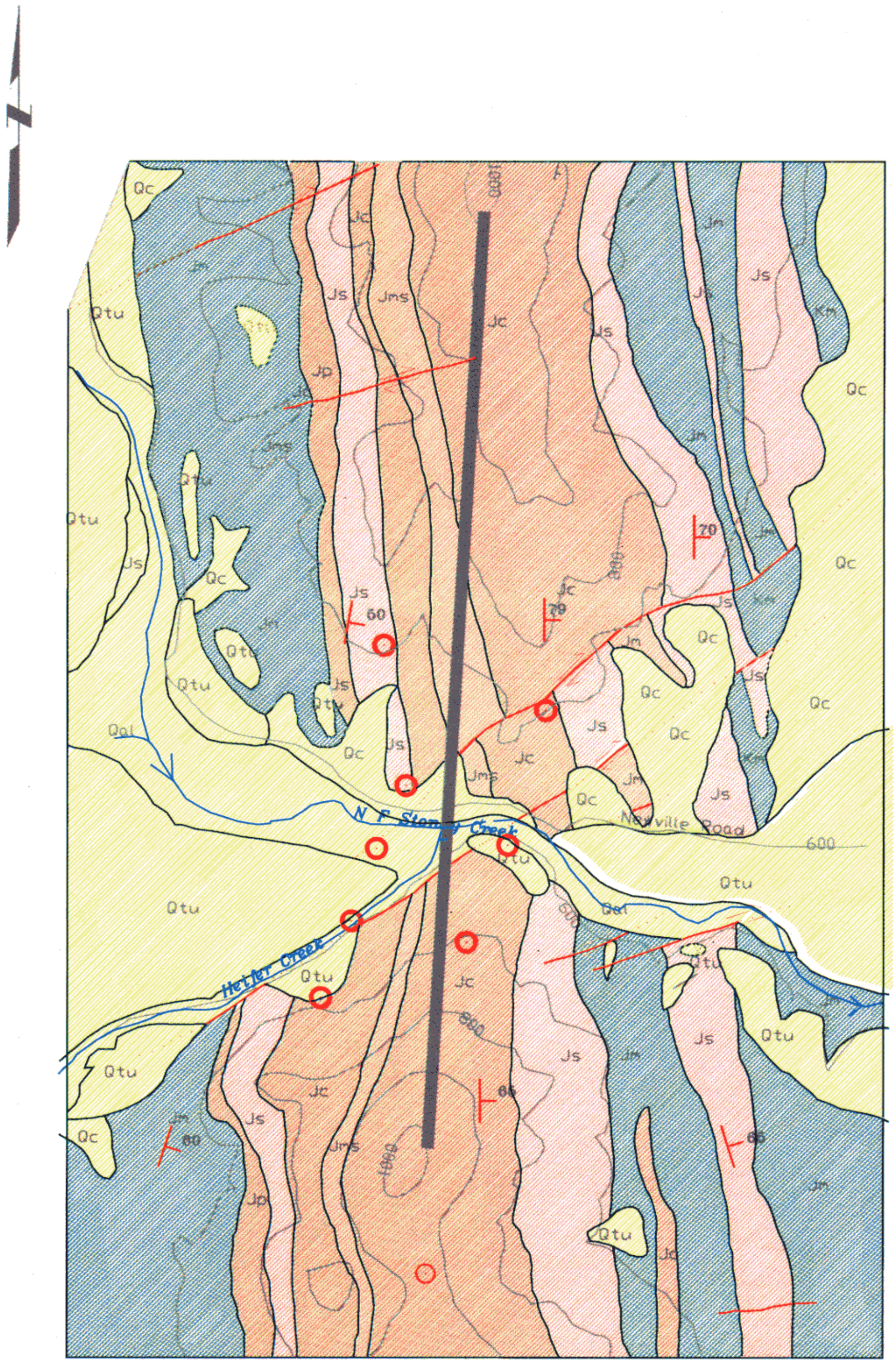
The Thomes-Newville Project consists of a 1.4 to 1.9 maf reservoir created by Newville Dam, a diversion dam on Thomes Creek, conveyance facilities to the reservoir, and Tehenn Reservoir, an afterbay with a pumping-generating plant. Additional facilities would be needed to bring water in from Black Butte Reservoir and the Sacramento River. The plan and geologic conditions were described in detail by DWR (1980).

A fault and seismic investigation was completed by ESA (1980). ESA concluded that none of the numerous well defined, dated, Quaternary terraces in the area show any topographic expression of offset by faulting or deformation by tectonic stresses.

Even the Pliocene Tehama formation that caps the ridges east of the reservoir area shows no signs of tectonic activity. The two critical structures proposed for this project are the Newville Dam and the Burrows Gap Saddle Dam. Figure 12 shows the damsite geology and the locations of faults.

Newville Dam Site

The Newville Dam site is about 20 miles west of Corning on North Fork Stony Creek where the creek crosses Rocky Ridge. The dam would be a 288- to 325-foot-high earth-rockfill structure. The dam would be founded on sandstone, mudstone, and conglomerate of the Jurassic Stony Creek formation and Cretaceous mudstones of the Lodoga formation. The units strike N-S and dip 50 to 80 degrees to the east.

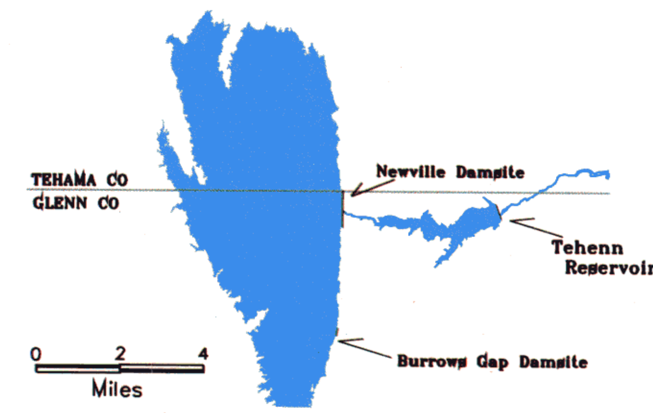


Newville Damsite

0 200 400 600
Feet
Contour Interval = 100 feet

Burrows Gap Damsite

Contour Interval = 20 feet



Location of Proposed Project Features

Legend

Quaternary Deposits

- Qal — Recent alluvium – mostly sand, gravel, and cobbles; includes small exposures of bedrock.
- Qc — Colluvium
- Qtu — Terrace deposits – mostly sand, gravel, and cobbles mantled by clayey soil.

Great Valley Sequence

Lodoga Formation

- Km — Mudstone

Stony Creek Formation

- Jc — Conglomerate with lenses of mudstone.
- Jm — Mudstone
- Jp — Pebbly mudstone grading to conglomerate
- Jms — Interbedded mudstone and sandstone
- Js — Sandstone with few beds of conglomerate and mudstone

- Geologic Contact, Dashed where Approximate
- 86 — Strike and Dip of Bedding
- Fault, Dashed where Approximate, Dotted Where Concealed Arrows Showing Direction of Movement, Queried where Questionable
- BRC-2 — Drill Hole Location
- Dam Axis

Geology from Thomes–Newville and Glenn Reservoir Engineering Feasibility DWR Report, 1990

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NORTHERN DISTRICT

Thomes – Newville Reservoir Project

Damsite Geology

Colluvium, alluvium, and terrace deposits cover about 20 percent of the foundation. The colluvium is generally less than 5 feet thick except at the base of the slopes where depths to 15 feet are reached. Gravelly deposits to 5 feet thick cover parts of the stream channel. Terrace deposits are the most abundant, and cover large areas both upstream and downstream of the dam axis. The terraces consist of 5 to 20 feet of sandy clay overlying a silty-to-clayey sand and gravel from 3 to 15 feet thick.

There are five faults crossing the foundation area. These are all roughly parallel, striking N50E across the regional bedding. The faults show apparent right-lateral movement and dip steeply. The faults appear to widen and branch irregularly in the mudstone beds. Diamond core drill holes encountered closely fractured and slickensided rock with numerous mud seams. Caving and sloughing were severe.

Complex fault movement makes the total amount of displacement difficult to determine, but it could be as high as 4,000 feet along the fault parallel to Heifer Creek. ESA (1980) placed four trenches across these features. The faults appeared to be confined to the Jurassic and Cretaceous bedrock and were considered to be pre-Tehama formation in age (3.3 mya). None showed any evidence of Quaternary-to-Recent movement.

The faults range in width from a few feet to over 40 feet and typically consist of highly fractured rock with seams of mylonite. Some faults have been cemented with calcium carbonate.

Burrows Gap Dam Site and Chrome Dike

Only a minimal amount of mapping has been done at these damsites. Burrows Gap Dam site foundation rocks consist mostly of sandstone and conglomerate with mudstone occurring on the upstream and downstream sections. Several NE-trending faults with minimal movement cross the foundation area. Chrome Dike is founded mostly on mudstone and Quaternary deposits. The Stony Creek fault trends just west of the right abutment. No trenching or drilling has been done at either damsite.

Sites Project

The Sites Project would be either a 1.2 maf smaller project or a 1.9 maf larger project about 10 miles west of Maxwell in the Antelope Valley. The project would consist of Sites Dam that would dam Stone Corral Creek, Golden Gate Dam that would dam Funks Creek, and an additional 5 to 12 saddle damsites across low areas along the reservoir rim. USBR has investigated the construction materials (1981) and engineering geology for the Sites Project (1969). Brown and Rich (1961) produced the *Geologic Map of the Lodoga Quadrangle, Glenn and Colusa Counties, California*, which includes the geology of Sites and Golden Gate Dam sites, and the Hunters and Logan Dam sites of the Colusa Project.

General geologic structural trends of bedding, folding and some faulting are N-NW, with most of the cross faults trending NE-SW across the prevailing structural trend.

The Salt Lake fault is a major structural feature that trends within a mile of most of the damsites in the Sites and Colusa Projects and possibly through the Sites Dam site. Most of the fieldwork and aerial photography analyses in Phase II will be directed at this fault.

The fault is a thrust that developed on the eastern limb of the doubly plunging, west-vergent Sites anticline (DWR 1978). Salt water springs, gas seeps, and sag ponds on the fault trace suggest the possibility of recent fault activity. In several locations, however, the fault is concealed by unbroken Pliocene Tehama formation, suggesting that the latest movement occurred prior to this time. Quaternary terrace deposits near and over the fault do not appear to be deformed (WLA 1997).

Preliminary field work and aerial photo analyses for this study suggest that the fault is not a trace, but a zone of subparallel shears, faults, and folding that may be wider than the mapped trace. It is therefore possible that movement has occurred since the Pliocene period on one of the fault traces.

Exposures are generally poor across the Salt Lake fault. Some geologic detail can be seen along Stone Corral and Funks Creeks, but the section is incomplete. Exposures at Stone Corral Creek directly west of the town of Sites shows fractured rock with numerous shears, folding, discontinuities in bedding, and faulting.

At Funks Creek, most of the Cretaceous bedrock is below the thalweg of the creek and not exposed. Some bedrock is exposed along the fault trace mapped by Brown and Rich (1961). Black discoloration, probably caused by seepage of gas and hydrothermal fluids, occurs on a number of these outcrops. Farther to the east, toward the Golden Gate Dam site, numerous shears, dislocations, and highly fractured rock are exposed. Several zones of mylonite also occur. The most probable location of major fault activity occurs along a linear valley directly to the west but has no bedrock exposures. Poor or no exposures occur along the Salt Lake fault where it crosses Logan Creek or Hunter Creek.

Sites Dam Site

Sites Dam site is underlaid by Upper Cretaceous interbedded sandstone, mudstone, and conglomerate of the Cortina formation. Within the reservoir area to the west, Cretaceous Boxer formation beds are folded by the Sites anticline. Beds at the damsite strike NNW and dip 40 to 60 degrees east. The predominant unit in the foundation is massive sandstone and associated thin-bedded sandstone, siltstone, and claystone of the Venado sandstone member.

Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium occurs in the stream channel. Terrace deposits are the most abundant, occurring both above and below the dam axis. The terrace deposits typically range in depth from 15 to 30 feet. Colluvium averages about 5 feet on the foundation area but may reach depths of 15 feet at the base of the slope. One small landslide occured on the left abutment and a larger slide occured on the right abutment. The larger landslide deposit is probably about 30 feet thick at the base but thinner at the top. It is in the range of 200 feet high and about 75 feet wide at the base. The landslide also covers the trace of fault S2 on the right abutment. Figure 13 shows the geologic map that was developed by

USBR (1969) and modified by DWR (1998) to show an additional fault and several landslides.

Faults at Sites include faults S1 and S2. S2, mapped by Brown and Rich (1961), extends from near the vicinity of the town of Sites, trends northeast through the right abutment, crosses the channel near the dam axis, and then extends downstream on the left abutment. The fault is several miles, possibly up to 5 miles, long. The fault shows apparent right lateral displacement and possible vertical displacement with the north side up.

Fault S1 was not mapped by Brown and Rich (1961) or by USBR (1969). It was mapped by WLA (1997) as a thrust fault. It crosses the left abutment, then the channel near the dam axis, and trends to the southeast across the right abutment. There is a possibility that S1 is a southward extension of the Salt Lake fault, which is shown by Brown and Rich to terminate about 2 miles north of the damsite.

The Salt Lake fault follows the axis of the Sites anticline, a major, doubly plunging, nearly isoclinal anticline on the west side of Logan Ridge. The anticline and the Fruto syncline to the west extend a distance of at least 40 miles and possibly farther.

The Salt Lake fault is a high-angle reverse fault or a thrust fault that developed adjacent to the axis of the anticline (DWR 1978). Salt water springs, gas seeps, and sag ponds occur along the fault trace. In several locations, the fault is concealed by unbroken Pliocene Tehama formation, suggesting that the latest movement occurred prior to deposition of the Tehama formation (3.3 mya) in these areas (USBR 1969).

The presence of this possibly active fault in the foundation at Sites is a concern and will therefore be a major part of the Phase II field investigation. It is also believed that the surficial folding and faulting is a result of deep-seated thrust faulting along the Great Valley thrust fault system.

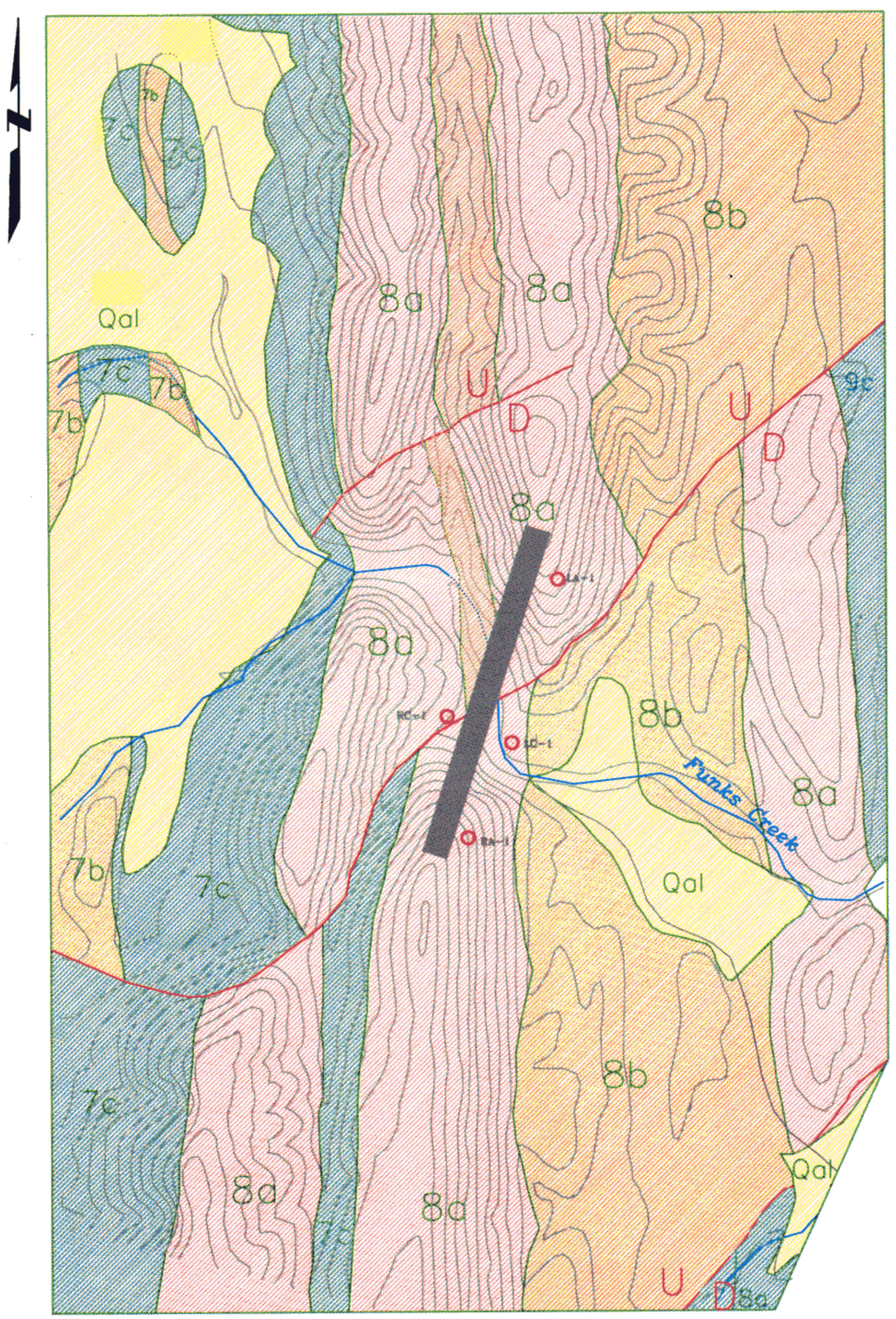
Golden Gate Dam Site

There are three damsites at Golden Gate: an upper site that was mapped and drilled by USBR in the 1960s, best for a small Sites Reservoir, and two lower sites that have not been investigated previously that are best for a large Sites Reservoir. The lower sites are the focus of this study. The damsites are on the same ridge as Sites Dam and only a few miles to the north, resulting in similar bedrock geology of predominant sandstone with interbedded mudstone and some conglomerate.

Quaternary to Recent deposits include colluvium, alluvium, landslide, and terrace deposits. Stream gravel deposits are minor and range in thickness to about 5 feet. Colluvium typically ranges from 5 feet to about 15 feet at the base of the slopes. Several landslides have occurred: one small recent one on the right abutment, and a larger older one on the left abutment. Terrace deposits are the most extensive, mostly Upper Modesto and Lower Riverbank formations. These average 15 to 20 feet thick, but may reach a thickness in excess of 25 feet. The composition is variable, but generally consists of an upper layer of silt and soil, and a lower layer of clayey gravel and cobbles.

Several faults cross the foundation area. Faults GG1, GG2 and GG3 were mapped by Brown and Rich (1961). GG1 extends from the right abutment of

Figure 13

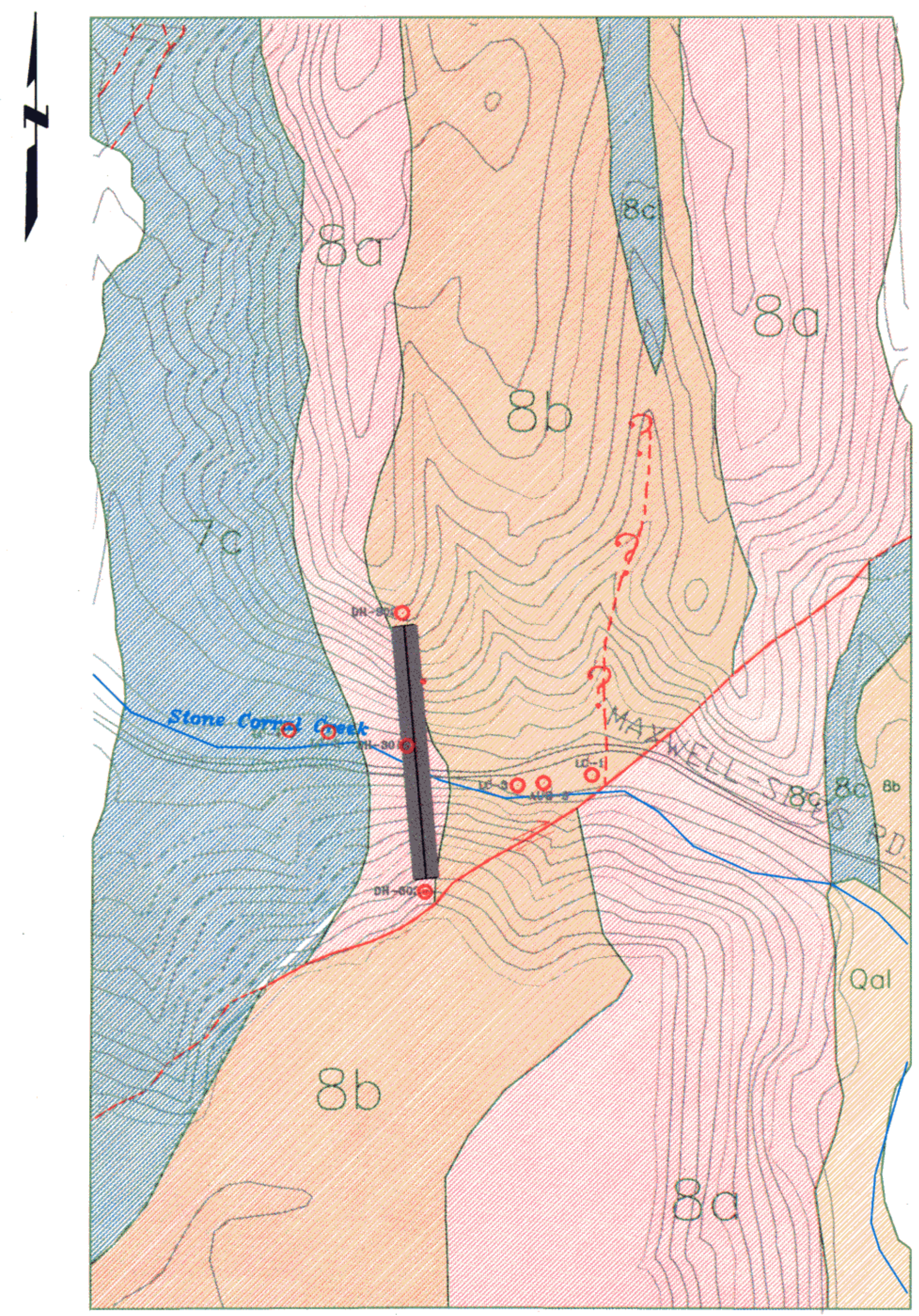


GOLDEN GATE DAMSITE

0 1000
Feet

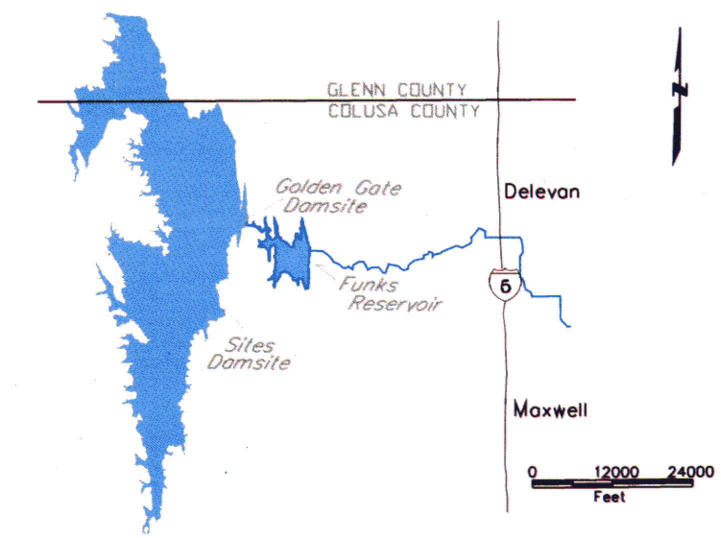
Contour Interval 10m

NOTE: Map has been generalized and simplified to show only regional geologic units and faults



SITES DAMSITE

0 500 1000
Feet
Contour Interval 10m



Proposed Project Location Features

Legend

Quaternary Units

- Qal — Quaternary Alluvium
- Qt — Terrace Deposits

Cortina Formation

- 9a — Sandstone
- 9b — Interbedded Sandstone and Siltstone
- 9c — Siltstone

Venado Sandstone Member

- 8a — Sandstone
- 8c — Siltstone
- 8b — Interbedded Sandstone and Siltstone
- 8d — Conglomerate

Boxer Formation

- 7a — Sandstone
- 7d — Upper Conglomerate
- 7b — Interbedded Sandstone and Siltstone
- 7e — Lower Conglomerate
- 7c — Siltstone

Geologic Contact, Dashed Where Approximate.
U/D — Fault, Dashed Where Approximately Located, Dotted Where Concealed, Queried Where Uncertain, U and D Showing Apparent Direction of Movement.
DWR Drill Hole Location
USBR Drill Hole Location
Dam Axis

USBR Sites Reservoir Report 1980

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Sites Project Damsite Geology

the two lower sites, crosses the channel slightly upstream of the dam axes, crosses the left abutment, and then extends an additional 2 miles in a NW direction before it ends or is lost in the mudstones to the east. Apparent right lateral displacement is estimated to be in the range of 0.3 mile.

Fault GG2 is much smaller and extends across the left abutment of the upper damsite, then trends NE and misses the left abutment of the lower damsite foundation by about one-fourth mile. Apparent right lateral displacement is estimated to be about 50 feet.

Fault GG3 is south of the damsite, but trends across the diversion alignment between Golden Gate and Funks Reservoirs. Displacement is estimated at about 1,500 feet.

Colusa Project

The Colusa Project would include the larger Sites Project, but would also expand northward into the Colusa compartment. Here Logan Dam would cross Logan Creek and Hunters Dam would cross Hunters Creek. In addition, a number of saddle dams would be required (Figure 14). No detailed geologic exploration has been conducted.

Hunters Dam Site

Brown and Rich mapped one fault crossing the left abutment. The north side is up, and apparent right lateral displacement is estimated to be less than 100 feet.

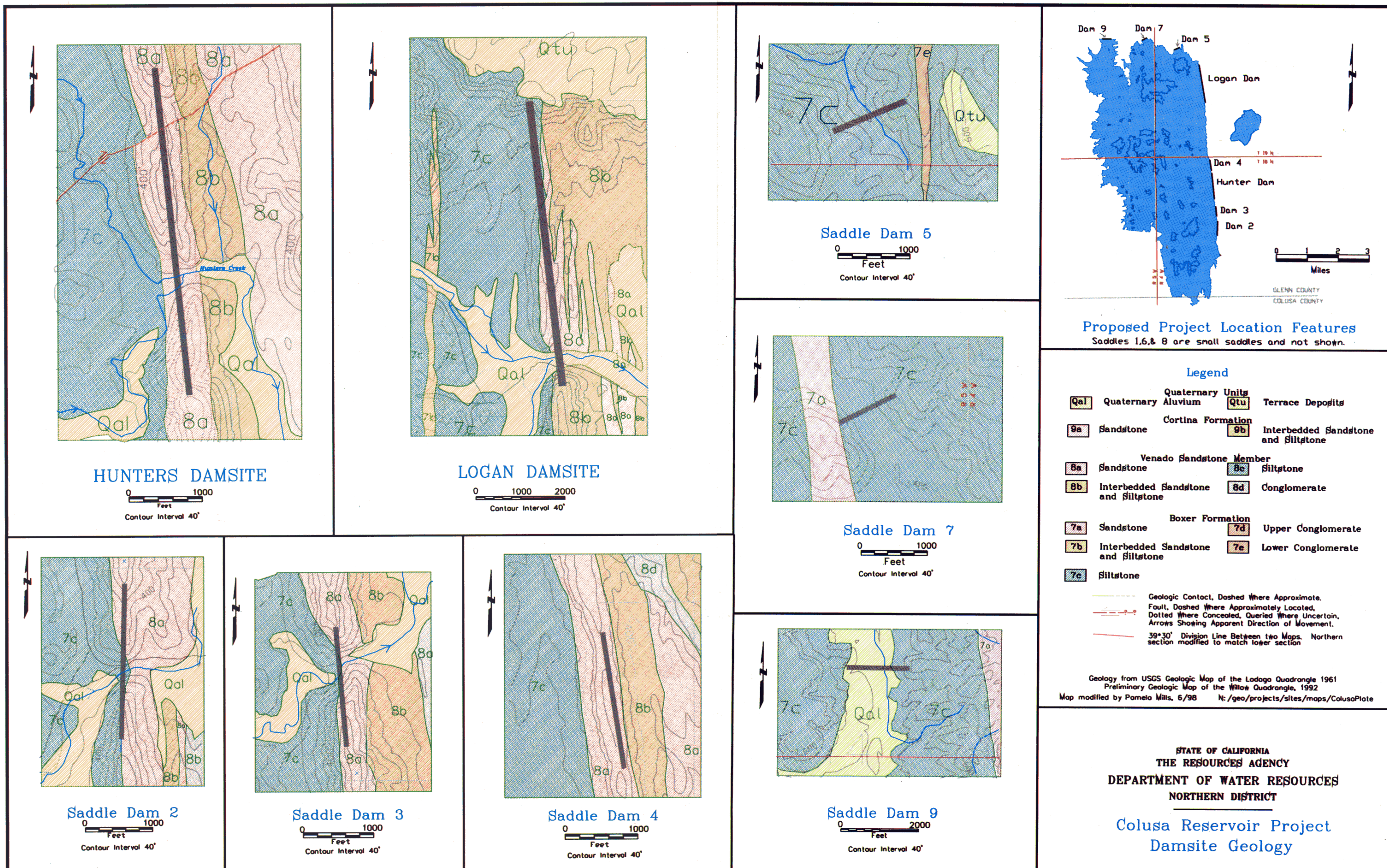
Hunters Dam site is on Logan Ridge, the same ridge as the Sites, Golden Gate, and Logan Dam sites. It is underlaid by Upper Cretaceous interbedded sandstone, mudstone, and conglomerate of the Boxer formation. Within the reservoir area to the west, the Cretaceous beds are folded by the Sites anticline. Beds strike NNW and dip 40 to 60 degrees east. The predominant unit in the foundation is massive sandstone and associated thin-bedded siltstone and claystone of the Venado sandstone member.

Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium occurs in the stream channel. Terrace deposits are the most abundant, occurring above, on, and below the dam axis. The terrace deposits typically range in depth from 15 to 30 feet. Colluvium averages about 5 feet on the foundation but may reach depths of 15 feet at the base of the slope.

Logan Dam Site

Logan Dam site is underlaid by the same bedrock units as all the other damsites. Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium occurs in the stream channel. Terrace deposits are the most abundant, occurring both above and below the dam axis. The terrace deposits typically range in depth from 15 to 30 feet. Colluvium averages about 5 feet on the foundation but may reach depths of 15 feet at the base of the slope. No faults were mapped by Brown and Rich at this site. Salt Lake fault is about 1 mile to the west.

Figure 14



HUNTERS DAMSITE
Hunters Creek
0 1000
Feet
Contour Interval 40'
LOGAN DAMSITE
0 1000 2000
Contour Interval 40'
Saddle Dam 5
0 1000
Feet
Contour Interval 40'
Saddle Dam 7
0 1000
Feet
Contour Interval 40'
Saddle Dam 9
0 2000
Feet
Contour Interval 40'
Saddle Dam 2
0 1000
Feet
Contour Interval 40'
Saddle Dam 3
0 1000
Feet
Contour Interval 40'
Saddle Dam 4
0 1000
Feet
Contour Interval 40'
Dam 9
Dam 7
Dam 5
Logan Dam
Dam 4
Hunter Dam
Dam 3
Dam 2
0 1 2 3
Miles
GLENN COUNTY
COLUSA COUNTY
Proposed Project Location Features
Saddles 1,6,& 8 are small saddles and not shown.
Legend
Quaternary Units
Qal Quaternary Aluvium
Qtu Terrace Deposits
Cortina Formation
9a Sandstone
9b Interbedded Sandstone and Siltstone
Venado Sandstone Member
8a Sandstone
8c Siltstone
8b Interbedded Sandstone and Siltstone
8d Conglomerate
Boxer Formation
7a Sandstone
7d Upper Conglomerate
7b Interbedded Sandstone and Siltstone
7e Lower Conglomerate
7c Siltstone
Geologic Contact, Dashed Where Approximate.
Fault, Dashed Where Approximately Located, Dotted Where Concealed, Queried Where Uncertain, Arrows Showing Apparent Direction of Movement.
39°30' Division Line Between two Maps. Northern section modified to match lower section
Geology from USGS Geologic Map of the Lodoga Quadrangle 1961
Preliminary Geologic Map of the Willow Quadrangle, 1992
Map modified by Pamela Mills, 6/98
N:/geo/projects/sites/maps/ColusaPlate
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
Colusa Reservoir Project
Damsite Geology

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Attachment A

Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects
Recorded by the Northern California Seismic Network
by
David Oppenheimer

United States Department of the Interior
GEOLOGICAL SURVEY
EARTHQUAKE HAZARDS TEAM
Seismology Section
345 Middlefield Road - Mail Stop 977
Menlo Park, California 94025
May 12, 1998
650-329-4792 (voice)
650-329-5163 (fax)
oppen@alum.wr.usgs.gov

Mr. Koll Y. Buer
Department of Water Resources
2440 Main Street
Red Bluff, CA 96080-2398

Dear Mr. Buer:

Enclosed find USGS Open-File Report 98-214 entitled "Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects recorded by the Northern California Seismic Network". I hope this report addresses your needs. If you have any additional questions about the seismicity of this region, please feel free to contact me.

You also requested information regarding the installation of additional seismic stations near the Red Bank project. We would appreciate knowing whether the DWR is still interested in pursuing this effort, as we would like to be able to plan for the installation.

Sincerely,

David H. Oppenheimer
Seismologist

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects recorded by the Northern California Seismic Network

by
David Oppenheimer[1]

Open-File Report 98-214

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

1998

1. Menlo Park, CA 94025

Seismicity near the Red Bank, Thomes-Newville, and Colusa Projects recorded by the Northern California Seismic Network

Introduction

This report briefly discusses the seismicity recorded by the USGS Northern California Seismic Network (NCSN) in the general vicinity of the California Department of Water Resources Red Bank, Thomes-Newville, and Colusa projects. Because of the relatively short monitoring interval (20-25 years) compared to the seismic cycle (100-1000's of years) of many faults in this region, it is very unlikely that most seismogenic structures in the region have been illuminated by the recorded earthquake activity during the interval 1975-1998. The low rate of seismicity in the eastern Coast Ranges, relatively high earthquake detection thresholds (discussed below), and the limited accuracy of the locations makes it difficult to define discrete faults based on alignments of hypocenters. Rather, it appears that most earthquake activity occurs on isolated and independent faults. Assessments of the seismic hazard should not be limited to interpretations of the seismic data and should also consider the strain rates and geologically active faults mapped in the region (Working Group on Northern California Earthquake Potential, 1996).

Because so little seismicity occurs within 25 km radius of the Red Bank or Thomes-Newville projects, the discussion of seismicity is, by necessity, general in nature. The regional seismicity may be considered representative of the type of seismicity that may be expected in the future, subject to the above caveat. Likewise, the minimum magnitude for uniform earthquake detection is based on the analysis of less than 100 earthquakes per region. Comparable analyses of larger regions surrounding the three sites, using hundreds of events, lead to similar minimum detection thresholds within a few tenths of a magnitude unit. All dates discussed in this report are UT.

NCSN operating procedures, station locations, and velocity models are described in Oppenheimer *et. al.* (1993). All hypocenters, focal mechanisms, phase information, waveforms, and station coordinates are available via the World Wide Web from *http://quake.geo.berkeley.edu/ncedc*. Maps of real-time earthquake information are available on *http://quake.wr.usgs.gov/recenteqs*.

Red Bank

Station Distribution and Detection Threshold

In the vicinity of the DWR Red Banks project there were few stations operating until June, 1975. Installation of seismic stations occurred gradually, and the network reached its current configuration by February, 1991, when 4 stations were installed for the California Department of Water Resources (solid squares, Figure 1). Since then, only one additional station west of Cottonwood has been installed in the region. Figure 2a indicates that for the interval 1978 - 1997 earthquakes above *M*2.2 within 25 km of Red Bank could be uniformly detected.

Seismicity

The histogram of earthquakes as a function of time within 25 km of Red Bank (Figure 3a) shows that the number of earthquakes located per month is typically 3 or less and often zero. The map and cross sectional views of seismicity (Figure 1, 4a) image three general features. There are few lineations expressed in this seismicity. In the eastern Coast Ranges scattered earthquake activity occurs within the crust to depths of 15 km. Northeast of Red Bluff at the eastern edge of the Great Valley, earthquake activity occurs at greater depths, approaching 30 km, reflecting the increased thickness of the crust due to the isostatic compensation effect of the Sierra Nevada range.

The earthquakes at depths greater than 30 km west of Red Bank image the subducting Gorda slab. Because of the small numbers of earthquakes during the period of observation and uncertainties in their locations, it is not possible to ascertain whether the earthquakes occur in the slab or on the slab interface. A *M*3.0 earthquake north of Cottonwood (April 3, 1985) that locates at a depth of 70 km also suggests that the slab extends beneath Red Bluff (Cockerham, 1984, Walter, 1986). Though it is unlikely that a mega-thrust earthquake on the Gorda - North America interface would rupture to such depths due to the thermal regime of the plate (Hyndman and Wang, 1995), the seismicity indicates that intraplate Gorda earthquakes are possible.

Thomes-Newville

Station Distribution and Detection Threshold

In the Thomes-Newville region the station coverage is poor. A station at Alder Springs (GAS) was installed in 6/1980, and a station to the north at Round Mt. (GRO) was installed 12/1990. There are no stations to the east within 70 km. The nearest stations is generally greater than 15 km from an epicenter. This degrades the accuracy of the hypocentral data in this region. In particular, the depths are relatively poorly determined compared to other regions of the network. Figure 2b indicates that for the interval 1976 - 1997 earthquakes above *M*2.1 within 25 km of Newville could be uniformly detected. With the installation of additional stations to the north of Newville in 1990-1991, the regional detection threshold decreased slightly to *M*1.9.

Seismicity

The histogram of earthquakes as a function of time (Figure 3b) shows that typically only one earthquake per month occurs within 25 km of Newville, but frequently there is no detected earthquake activity. There is scattered seismicity with 25 km of Newville, but no obvious structures defined by the seismicity. Beginning May 16, 1995 a small sequence occurred 18 km west of Newville. The aftershock activity ceased 3 days later. The largest event, which occurred on May 17, had a magnitude of M_D 4.2. The seismicity shown cross section B-B' (Figure 4b) indicates that the earthquakes occur within the crust, as described above in section A-A'.

Colusa/Williams

Station Distribution and Detection Threshold

In the Williams area station coverage is also poor. While station coverage has been uniform since late 1975, the nearest station (on Sutter Butte) is generally greater than 20 km from an epicenter. This degrades the accuracy of the hypocentral data in this region. Figure 2c indicates that for the interval 1976 - 1997 earthquakes above *M*2.3 within 25 km of Colusa could be uniformly detected.

Seismicity

The histogram of earthquakes as a function of time (Figure 3c) shows that earthquake occurrence within 25 km of Newville is rare. However, two separate, north-northwest trending faults are imaged by the alignments of hypocenters near Williams. Two first-motion focal mechanisms for events on Apr 18, 1985 (M_L3.7) and on Nov 26, 1980 (M_D3.2) indicate predominant right-lateral strike-slip motion on a fault plane parallel to the orientation of seismicity (Fig. 5). In cross section C-C' (Fig. 4c) the faults are near-vertical, consistent with the focal mechanisms, and they extend to depths of about 20 km. The April 18, 1985 sequence occurred 11 km southwest of Williams. Minor aftershock activity continued until late September, 1985 (Fig. 3c). The largest event of the sequence, the M_L 3.7 event, occurred on the first day.

References

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Hyndman, R.D., and K. Wang, The rupture zone of Cascadia great earthquakes from current deformation and the thermal regime, *J. Geophys. Res.*, *100*, 22,133-22,154, 1995.

Oppenheimer, D., F. Klein, J. Eaton, and F. Lester, The Northern California Seismic Network bulletin, U.S. Geol. Surv. Open-File Rep. 93-578, 45 pp., 1993.

Walter, S.R., Intermediate-focus earthquakes associated with Gorda plate subduction in northern California, *Bull. Seism. Soc. Am.*, *76*, 583-588, 1986.

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Acknowledgment

I thank Rick Lester for his careful review of this report and the staff of the NCSN who maintain, operate, and process the earthquake data recorded by the NCSN.

Figure Captions

Figure 1. a) Map of well-located seismicity recorded by the Northern California Seismic Network for the period July 24, 1973 through February 7, 1998. Data have been selected with the following typical quality parameters: RMS $\leq$ 0.3 sec, horizontal uncertainty $\leq$ 2.5 km, vertical uncertainty $\leq$ 5.0 km, maximum azimuth gap in station distribution $\leq$ 180°, # of stations $\geq$ 8. No magnitude selection were used. Due to sparse station spacing, the above selection criteria eliminated nearly half of possible 6063 earthquakes from the plot. Solid squares depict locations of seismic stations. Open triangles denote locations of labeled cities and towns. Rectangular, labeled boxes depict selection region for cross-sections. Irregular shaped bodies depict lakes and reservoirs. Faults near Ukiah and Lake Pillsbury are Holocene or younger (Jennings, 1992). Symbol size is proportional to magnitude.

Figure 2. Histograms of the *log(N)*, where N = number of earthquakes, as a function of magnitude for three areas shown in Fig. 1. The (solid) open squares are the (cumulative) number of earthquakes within 0.1 bins of magnitude. The magnitude detection threshold above which the seismic network is able to uniformly locate all earthquakes is indicated at the top of the plot as "MIN.MAG" and is manually chosen by examination as the point where the slope of the cumulative number of earthquakes departs from a straight line at smaller magnitudes. The line through the cumulative number of earthquakes is a least-squares estimate of the slope ("B" value) of the data greater than the detection threshold; "A" is the M=0 intercept value (*log(N)*). a) Red Bank region (Fig. 1, A-A'), b) Newville region (Fig. 1, B - B'), c) Colusa region (Fig. 1, C - C').

Figure 3. Histograms of earthquakes/month within 25 km of a) Red Bank (40° 06.00', 122° 26.00'), b) Newville (39° 47.00', 122° 31.00'), c) Colusa (39° 12.90', 122° 00.50'). No other selection criteria were used.

Figure 4. Cross sections of seismicity corresponding to earthquakes shown in Fig. 1. a) Red Bank region, b) Newville region, c) Colusa region.

Figure 5. Lower hemisphere, equal-area projection of fault plane solutions for earthquakes near Williams on a) 02:33 UTC, Nov 26, 1980 (M_D3.2) and b) 16:29 UTC Apr 18, 1985 (M_L3.7). Compressional and dilatational first-motion directions are indicated by circles and +'s, respectively. P and T symbols denote P-axis and T-axis, respectively. Three numbers adjacent to nodal planes correspond to strike, dip, and rake.

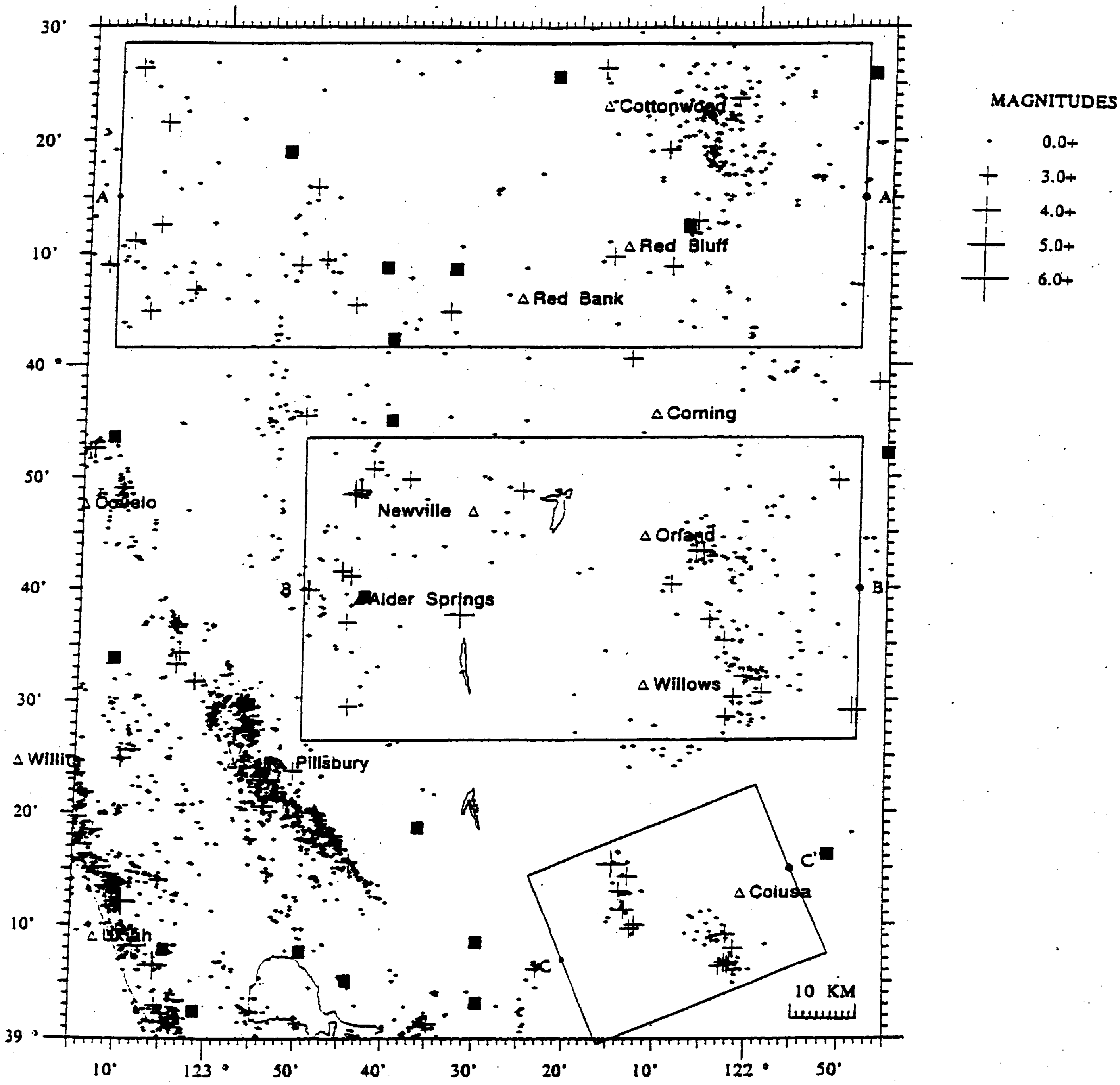

30'
20'
10'
40°
50'
40'
30'
20'
10'
39°
10'
123°
50'
40'
30'
20'
10'
122°
50'
A
A'
B
B'
C
C'
Cottonwood
Red Bluff
Red Bank
Corning
Newville
Orland
Alder Springs
Willows
Covelo
Willits
Pillsbury
Colusa
Ukiah
10 KM
MAGNITUDES
0.0+
3.0+
4.0+
5.0+
6.0+

Figure 1

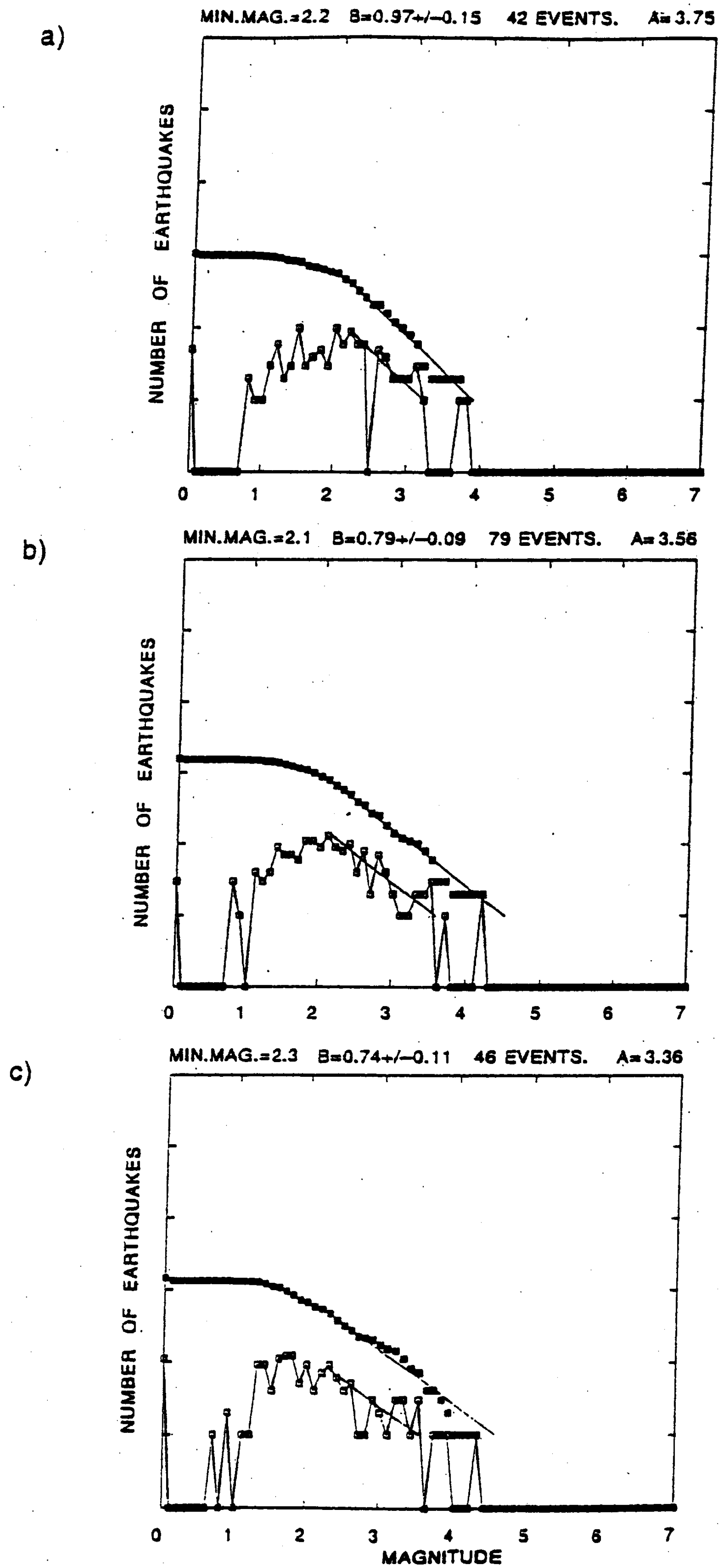

a)
MIN.MAG.=2.2 B=0.97+/-0.15 42 EVENTS. A=3.75
NUMBER OF EARTHQUAKES
0 1 2 3 4 5 6 7
b)
MIN.MAG.=2.1 B=0.79+/-0.09 79 EVENTS. A=3.56
NUMBER OF EARTHQUAKES
0 1 2 3 4 5 6 7
c)
MIN.MAG.=2.3 B=0.74+/-0.11 46 EVENTS. A=3.36
NUMBER OF EARTHQUAKES
0 1 2 3 4 5 6 7
MAGNITUDE

Figure 2

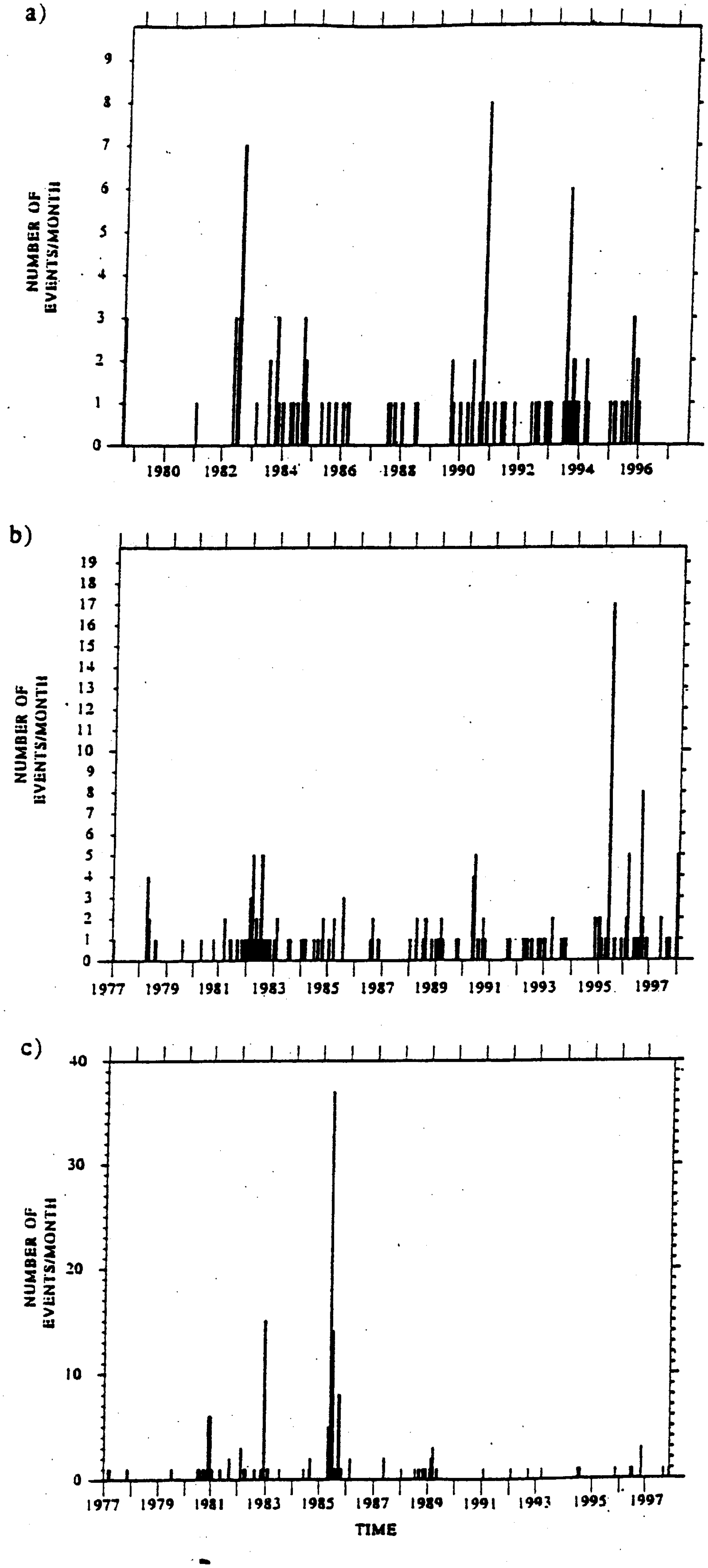
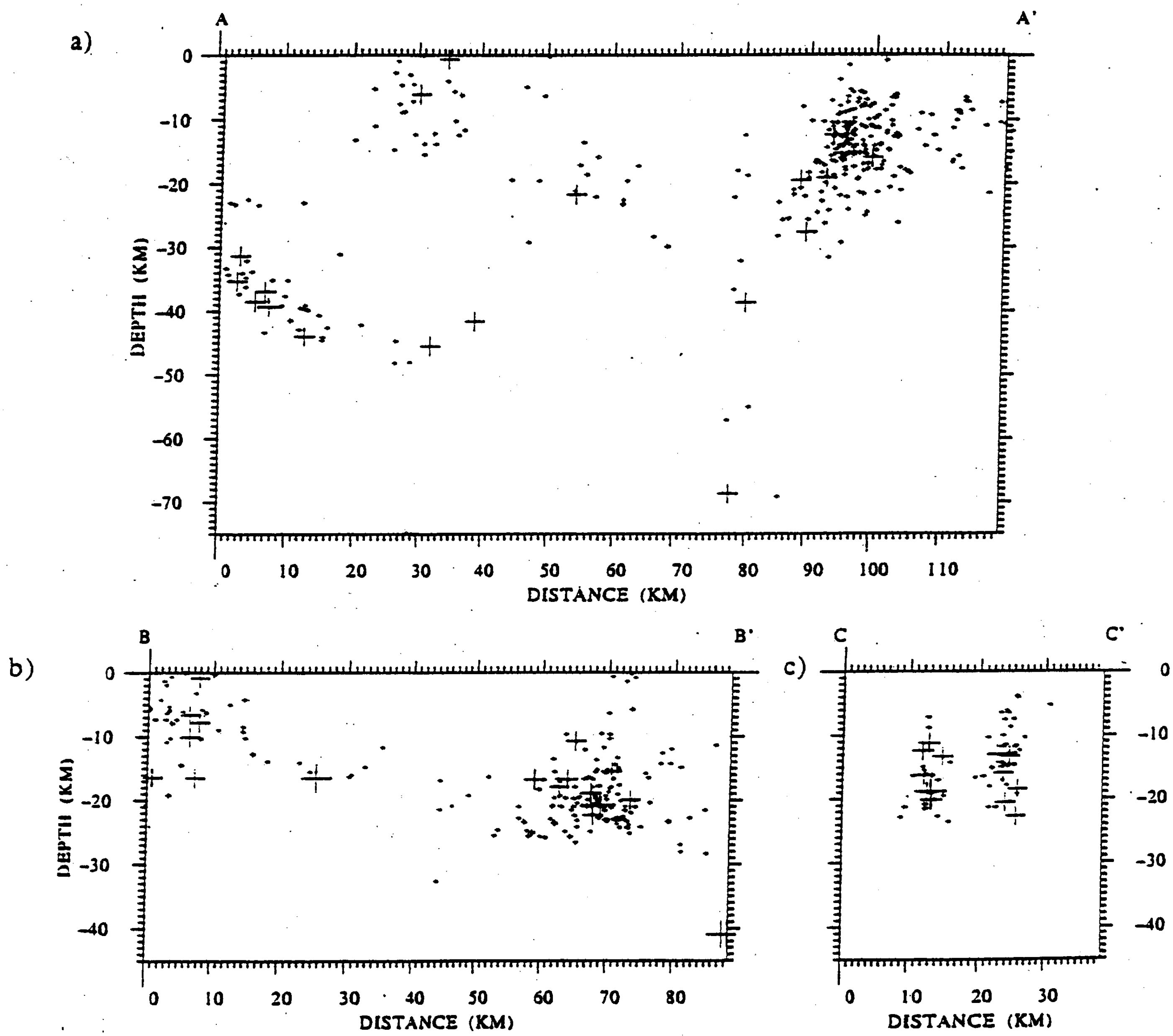

a)
NUMBER OF EVENTS/MONTH
0
1
2
3
4
5
6
7
8
9
1980
1982
1984
1986
1988
1990
1992
1994
1996
b)
NUMBER OF EVENTS/MONTH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
c)
NUMBER OF EVENTS/MONTH
0
10
20
30
40
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
TIME

Figure 3



a)
A
A'
DEPTH (KM)
DISTANCE (KM)
0
-10
-20
-30
-40
-50
-60
-70
0
10
20
30
40
50
60
70
80
90
100
110
b)
B
B'
DEPTH (KM)
DISTANCE (KM)
0
-10
-20
-30
-40
0
10
20
30
40
50
60
70
80
c)
C
C'
DISTANCE (KM)
0
-10
-20
-30
-40
0
10
20
30

Figure 4

a)

b)

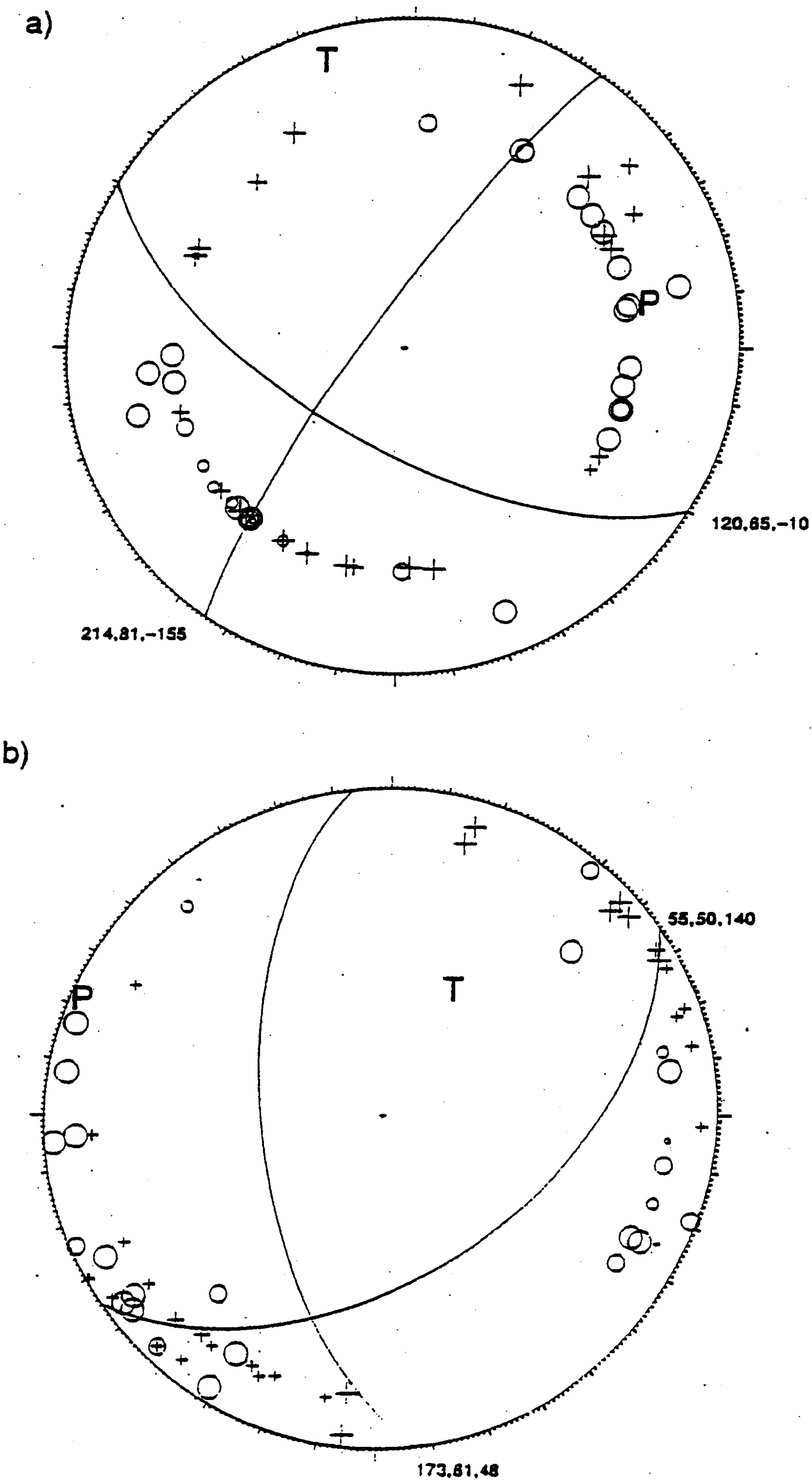


Figure 5

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Department of Water Resources, Thomas M. Hannigan, Director

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